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REVIEW OF
PERATIONAL URBAN TRANSPORTATION MODELS

PMM&Co.

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FINAL REPORT

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16. Abstract

This study compares and evaluates operational or near operational urban transportation planning models from the viewpoints of theoretical structure, application experience, cost of operation, effectiveness, and the availability of the model for public use. The models are discussed in regard to the roles they play in the urban transportation planning process. The following categories of models are reviewed: demand, network, cost-benefit/impact, and land use.

The report has two main sections. First, the 19 models are categorized, cross referenced, and compared in the body of the text, where the total urban transportation planning process is discussed. Second, each model is reviewed in a self-contained summary in the technical appendixes.

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TABLE OF CONTENTS

TABLE OF CONTENTS (CONT.)

TABLE OF CONTENTS (CONT.)

TABLE OF CONTENTS (CONT.)

LIST OF TABLES

LIST OF FIGURES

FOREWORD

This urban transportation planning model review was performed under the sponsorship of the Systems Analysis Division of the Transportation Systems Center (TSC) of the Department of Transportation. On behalf of TSC, Mr. Robert N. Tap monitored the technical progress of the project. Peat, Marwick, Mitchell & Co. (PMM&Co.) enjoyed working with Mr. Tap throughout this study.

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GLOSSARY OF ACRONYMS

BATSC	Bay Area Transportation Study Commission
CBD	Central business district
CCC	Comprehensive, cooperative and continuing planning programs
CDC	Control Data Corporation
CPU	Central processing unit
CRA	Charles River Associates
CRT	Cathode ray tube
DCO/TRANPLAN	DeLeuw, Cather & Co. Transportation Planning Programs
DODOTRANS	Decision Oriented Data Organizer Transportation Analysis System
FHWA	Federal Highway Administration
GRC	General Research Corp.
HUD	Department of Housing and Urban Development
HUDTRAN	HUD Transportation Planning Programs
ICES	Integrated Civil Engineering System
ITTE	Institute of Traffic and Transportation Engineering
MBTA	Massachusetts Bay Transportation Authority
MIT	Massachusetts Institute of Technology

MLUT	Model of Land Use and Transportation
NSRAP	New Systems Requirements Analysis Program
O-D	Origin-destination
OST	Office of Secretary of Transportation
PLUM	Projective Land Use Model
PMM&Co.	Peat, Marwick, Mitchell & Co.
PRT	Personal rapid transit
SNAP	SRI Network Analysis Programs
SRI	Stanford Research Institute
STOCH	Dial Stochastic Assignment Model
TOMM	Time Oriented Metropolitan Model
TRANS	Transportation Research Allocation Study
TRC	Traffic Research Corporation
TSC	Transportation Systems Center
UMTA	Urban Mass Transportation Administration
UPM	Urban Performance Model
USM	Urban Systems Model
UTP	Urban transportation planning
UTPS	UMTA Transportation Planning System

1. EXECUTIVE SUMMARY

BACKGROUND AND PROJECT OBJECTIVE

Planning is essential in the continuing development of viable urban transportation systems. Before making the capital commitments for sites, construction, and equipment, it is necessary to determine the feasibility, costs and benefits, and social and environmental impacts of proposed alternative systems. Recognizing the crucial need for planning, the Department of Transportation (DOT) has performed or monitored the following activities:

. A National Transportation Study was carried out in 1972 for all modes across the country.

. As required in conjunction with the National Transportation Study, all states have completed statewide plans to define future transportation needs.

. All urban areas over 50,000 population have underway comprehensive, cooperative, and continuing planning programs, as required under Section 134 of the Federal Highway Act. Multimodal analyses to aid in long-range transit planning have been carried out for most urban areas over 250,000 population.

Transportation analysis tools have been developed with diversified emphasis by different institutions—government agencies, consulting organizations, research institutes, and universities—and new techniques are evolving at a rapid pace. Periodic review and dissemination of the new developments are clearly necessary. This report, a state-of-the-art review of urban transportation planning models, was initiated by DOT's Transportation Systems Center (TSC). Peat, Marwick, Mitchell & Co. (PMM&Co.), under contract to the Systems Analysis Division of TSC, has carried out this study.

PMM&Co.'s study compares and evaluates operational or near operational urban transportation planning models to

determine their purposes, effectiveness, scope, and cost. This report provides summaries and detailed descriptions of models suitable for a variety of analytical purposes. The analyst will find the report a useful tool for quickly assessing the applicability, resource requirements, and theoretical soundness of the models in relation to the specific problems to be investigated. Models recommended by the study are capable of providing comprehensive and comparable measures of efficiency, quality, and impacts for a variety of urban transportation systems in a metropolitan area.

MODEL REVIEW

The categories of urban transportation planning models reviewed by PMM&Co. were demand, network, cost-benefit/ impact, and land use. The classification of models into these categories is useful for a systematic presentation. A model may, however, fall into more than one classification, and all models interact with each other in the urban transportation planning process. The models reviewed are therefore discussed in two ways: the body of the report considers their interrelationships, and Appendixes A through D review the models individually. PMM&Co. believes that the readers of the reviews can gain a practicable knowledge of each model without referring to other literatures.

A comprehensive list of models was considered in the project, from which the following were selected for detailed review:

Demand Models

Trip Generation Model
Gravity Model
Intervening Opportunity Model
TRC Modal Split Model
Pratt Marginal Utility Model
Lisco Probit Model
n-Dimensional Logit Model
Economic Demand Model

Network Models

FHWA Network Programs
UMTA Transportation Planning System (UTPS)
  Network Programs
DCO/TRANPLAN Network Programs
Dial Stochastic Assignment Model

Cost-Benefit/Impact Models

DODOTRANS
Transportation Resource Allocation Study (TRANS)
SRI Network Analysis Program (SNAP)

Land Use Models

Projective Land Use Model (PLUM)
Urban Systems Model (USM)
EMPIRIC Land Use Model
Accessibility-Opportunity Model
Urban Performance Model (UPM)

FINDINGS AND RECOMMENDATIONS

Current urban transportation planning techniques usually require an extensive data base, coding of detailed networks, and use of a costly set of computer programs. Approximately 70 percent of urban planning funds are devoted to data and model preparation, with less than 20 percent devoted to plan evaluation and testing. Because of the onerous nature of the techniques, the analysis of an urban transportation plan requires from 12 to 24 calendar months. It seems logical, therefore, that the most meaningful direction for analytical technique development would be to emphasize sketch planning models requiring less computational expenditure or data base development than current models. This would allow a faster analysis "turnaround" time, resulting in a planning procedure which is more responsive to issues and problems. More resources could then be apportioned to exploring and evaluating a larger number of alternatives. PMM&Co. makes the following recommendations:

- An aggregate, instead of detailed, modeling approach would place less demand on excessive data bases or the coding of detailed networks, and in general would cut down on the analysis resources devoted to model preparation.

- An interactive planning technique, such as use of graphic terminals, on which the aggregate models could be implemented, promises to be a far more effective means to interface between the analyst, the model, and the decision-maker than the batch-processing systems currently used.

Examples of these approaches can be found in the development of the TRANS Model and the UMTA (Urban Mass Transportation Administration) Transportation Planning System, both of which are reviewed in this report.

2. BACKGROUND OF MULTIMODAL TRANSPORTATION PLANNING

Major emphasis has been placed on the ability to plan all modes of transportation at all levels of government, federal, state, and local. The U.S. Department of Transportation is especially interested in the development of nationwide requirements statements on the investments in multimodal transportation systems. The first National Transportation Study (NTS), in 1972, was undertaken to quantify the nation's existing transportation systems and future planned transportation systems in terms of a set of consistent nationwide measures. The results of this study are just now available and have been submitted by the Secretary of Transportation to Congress.

Improvement of the overall transportation planning process at all levels of government is critical. A thorough documentation of the present state of the art of transportation planning is necessary, and this project undertaken for the Transportation Systems Center by Peat, Marwick, Mitchell & Co. contributes significantly to the general knowledge of urban transportation planning and urban planning models.

NATIONAL PLANNING

The NTS was effective in delineating future nationwide transportation needs. The data were developed through an extensive survey of state and local government agencies, which individually documented their needs for 1980 and 1990. Through studies conducted jointly by the Office of the Secretary of Transportation and the Federal Highway Administration (FHWA), the Transportation Resource Allocation Study (TRANS) Model analyzed this data to develop independent forecasts of transportation needs (highways and public transit) in over 300 urban areas.

STATE PLANNING

The objectives of state-level transportation planning include preparation of recommendations on level of investment in all modes, location, type of facility, level of

service, timing, and relation to certain external factors such as land use, the economy, and the environment. All states, as required in conjunction with the NTS, have completed statewide plans to define future transportation needs. A single-mode evaluation approach using planning models is now underway in about 20 states, and 8 states are in the process of developing and applying statewide highway traffic assignment models. Connecticut and Rhode Island have completed highway assignments. No state has yet conducted a multimodal traffic simulation-evaluation approach, which forecasts demand (people and goods), allocates demand among the modes, and produces multimodal traffic assignments.

LOCAL PLANNING

All urban areas over 50,000 population have underway comprehensive, cooperative and continuing (CCC) planning programs as required under Section 134 of the Federal Highway Act. In all programs, the FHWA Planning Models have been applied to forecast traffic demand and produce traffic assignments. Some multimodal planning has been applied: the percentage of transit usage has been estimated and transit assignments prepared to aid in long-range transit planning for most urban areas over 250,000 population. The UMTA Transportation Planning System (UTPS) is being used increasingly for public transit route and service planning. Typical costs to conduct the CCC planning have ranged between $1 per capita in small urban areas to $3 in large urban areas. Over 70 percent of the expenditure has been employed in data collection and development of urban planning models. Transit technical planning studies have cost, on the average, 10 to 50 cents per capita.

SUMMARY

The above discussions on national, state, and local planning mention some of the models commonly used in the profession. In the National Transportation Study, an aggregate model, TRANS, was used extensively. TRANS has the advantage of being economical to use, and it is tailored especially for cost-benefit/impact analysis (hence lending

itself to resource allocation functions). The cornerstone or urban transportation modeling remains, however, the FHWA package of programs. Transportation planning has historically been auto-oriented; this tends to favor the usage of the FHWA package. The fact that the package has been in existence longer and hence is more widely known than most of the other models also propagates its use. It was only recently, when transit travel became an unavoidable part of the work trip, especially in congested high-density cities, that a transit-oriented model like UTPS was developed. More and more urban areas find it necessary to conduct multimodal planning. This means that UTPS will gradually command a more important role in urban transportation planning.

3. PROJECT OBJECTIVES AND SCOPE

EVALUATION OF URBAN TRANSPORTATION PLANNING MODELS

The growth of urban transportation planning in recent years has accelerated the development of improved urban transportation planning models. Many of the older models exhibited rigidly structured formats, required large amounts of data, and resulted in less than optimal solutions. New techniques often demonstrate greater flexibility, operate on smaller amounts of selectively prepared data, and in some cases, make use of mathematical programming algorithms which lead to "optimal" solutions. The direction of new modeling efforts has been influenced by the following factors:

- The increasing number of new transportation systems being considered in both short- and long-term planning efforts, ranging from new-technology vehicles and guideways to new uses of conventional transit facilities, is pointing toward the development of more generalized models that can be employed with many different types of modes.

- The large number of cases often proposed for analysis has led to a desire for planning tools which enable the evaluation of many alternatives in a short time while maintaining a valid level of significance.

- Because new modes often present a real transportation alternative to the trip-maker in terms of both the quality and quantity of service, new models must be potentially sensitive to parameters such as comfort, safety, and reliability, in addition to the usual time and cost variables.

The variety of models utilized in transportation planning today has increased as the awareness of the breadth of impacts of transportation systems has expanded. Past emphasis on economic costs and benefits is being replaced by almost equal consideration of economic, environmental,

and developmental impacts, leading to the development of new cost-benefit and urban impact techniques, which are relative newcomers to the transportation planning field.

Finally, the continuing development of both hardware and software technology, including larger, faster computers and interactive graphic techniques, is providing new areas for exploration. It is apparent that the rapid growth in model development and application will continue in the next few years.

Because the urban transportation planning field encompasses an extremely wide variety of skills, there has been no centralized forum for the dissemination of information on advances in transportation modeling. Papers presented at diverse conferences usually reach only a fraction of potentially interested parties. Since these papers vary in depth and objectivity of reporting, comparisons among techniques are difficult to make. Standards for evaluation criteria are virtually nonexistent.

From time to time, reviews of certain kinds of planning models, such as land use or modal split, have been published. However, no comprehensive study of all model types has ever been carried out. Consequently, model interfacing, in terms of machine compatibility, data requirements, significance levels, etc., have been given little attention. Also, information on costs of application has often been unavailable or spotty. This study provides the information necessary for the selection of a model or system of models for most applications.

URBAN MODEL REVIEW CRITERIA

Models were selected for evaluation based on the requirements prescribed by TSC. Two overriding criteria were applied:

- Models should be "operational or near operational." Theoretical models were ruled out and were not evaluated. The definition of "near operational" was judgmental and depended on what preliminary or interim documentation was available.

- Models that are obsolete because of outdated theory or hardware should not be evaluated. Models that have been updated and improved in later applications should not be evaluated in their original versions.

In addition, the selected models should be sensitive to the attributes of different transportation technologies. (However, subtle differences between closely related modal types—such as demand-responsive personal rapid transit (PRT) and scheduled PRT—need not be distinguishable.) Emphasis was also placed on the potential usefulness of the model. Wherever possible, rejected models were cataloged to indicate that they were investigated and discarded, rather than overlooked.

The model characteristics that were scrutinized include the following:

- Data Requirements
  - types
  - quantity
  - format
  - availability
- Hardware Requirements
  - machine type
  - machine size
  - availability
- Logic of Structure and Conceptual Appeal
- Ease of Calibration
  - data requirements
  - convergence

- Effectiveness
    - accuracy
    - significance
    - sensitivity to system attributes
    - repeatability
    - interpretation of results
- Flexibility
    - application to different modes and areas
    - future modifications and improvements
    - levels of detail
    - problem size
- Kinds of Output Available
- Cost of Operation
    - manpower requirements
    - machine dollars
- Experience/Success to Date
- Availability (Private or Public Domain)
- Compatibility with Other Models and Model Types

The following reporting format was used for the model evaluations:

- source
- where and when used
- brief theoretical description

- description of model characteristics

- overall appraisal and recommendations

In addition, summary tables were prepared to highlight the most important criteria of the models reviewed.

4. MODEL REVIEW

MODELING THE TRANSPORTATION PLANNING PROCESS

Standardized procedures exist for the analysis of urban area transportation systems. The Federal Highway Administration, the Urban Mass Transportation Administration, and recently the Office of the Secretary (OST) have developed software packages. Although the packages tend to be tailored for a particular mode or with special emphasis, they generally are flexible enough to analyze a variety of transportation options.

The categories of urban transportation planning models used in this report are: land use, demand, network, and cost-benefit/impact. Brief definitions of these labels are as follows:

- Land Use Models: For an urban area, land use models forecast the growth of socioeconomic activities and allocate these activities among the different parts of the area.

- Demand Models: Demand models estimate the potential desire for travel between all the origin-destination (O-D) points in the model of an urban area.

- Network Models: Network models simulate the traffic flow and service/performance characteristics of an urban network under certain operational, pricing, and regulatory conditions.

- Cost-Benefit/Impact Models: Cost-benefit/impact models measure the characteristics of alternative transportation plans and their respective abilities to satisfy community goals and objectives.

The traditional urban transportation planning (UTP) procedure uses the above four classes of models in sequence, with the output from one model serving as input to the next.

Figure 1 shows the UTP sequence used in studies (such as the classic Detroit study) as early as 1953.

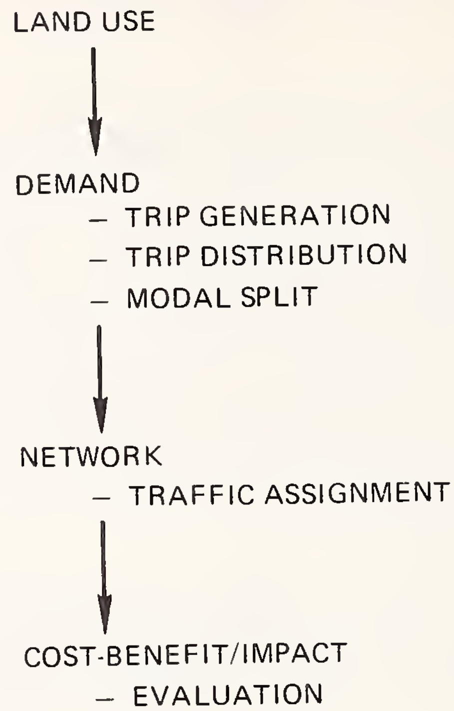

FIGURE 1: URBAN TRANSPORTATION PLANNING SEQUENCE

Some of the terminologies used in the traditional UTP process are not exactly the same as those used in this report. Instead of demand models, practitioners refer to the three specific components of demand estimation: trip generation, trip distribution, and modal split. Network models are called traffic assignment procedures. Cost-benefit/impact analysis is called evaluation.

The sequential steps constitute a practical and straightforward method for planning. However, feedbacks or interactions between the various steps are necessary for a more meaningful analysis. For example, the coupling relationship between land use and transportation—that the transportation system affects land use, and that the land use pattern poses a requirement for transportation—is not modeled in the UTP of Figure 1.

Although the classification of models into land use, demand, network and cost-benefit/impact categories is useful for a systematic presentation, it is somewhat arbitrary. Frequently, a model could be both a network and evaluation model (for example, DODOTRANS or SNAP). Moreover, since the classes of models interact with one another, it is impossible

to discuss a class of models in isolation without making reference to the other classes. To emphasize the feedback interactions between the different classes of models, a block diagram is presented in Figure 2.

In the upper left-hand corner of Figure 2, "activity system" is marked. Activity system means the socioeconomic pattern of the urban area under consideration, from which the travel demand can be estimated. Instead of estimating demand directly from the activity system, it is often more satisfying, especially in long-term forecasting, to predict future land use first, and then to derive future travel demand for the land use pattern.

Borrowing from the demand/supply paradigm of economics, the "supply" side of transportation systems is represented by the network. Network refers to the right-of-way system (whether it be rail, streets, highways, or guideways), the fleets of vehicles, and the operating, pricing, and regulatory policies. An exogenously imposed transportation policy specifies the network options for the transportation plan, with the associated resource requirements.

Demand is then flowed over the network options (a process usually referred to as equilibration), resulting in the equilibrium condition. When equilibrium is reached, the system is characterized by a particular flow pattern, certain levels of service and pricing, and certain socioeconomic activity changes. The cost-benefit/impact model converts these equilibrium attributes, and the resource requirements for the particular network option, into cost-benefit/impact measures. The changes in activity pattern are fed back to affect the changes in land use and demand, which in turn motivate changes in the transportation "supply" policies.

With these interactions in mind, we can go on to consider each category individually.

DEMAND MODELS

In the urban transportation planning context, demand models refer to the techniques that estimate travel potentials

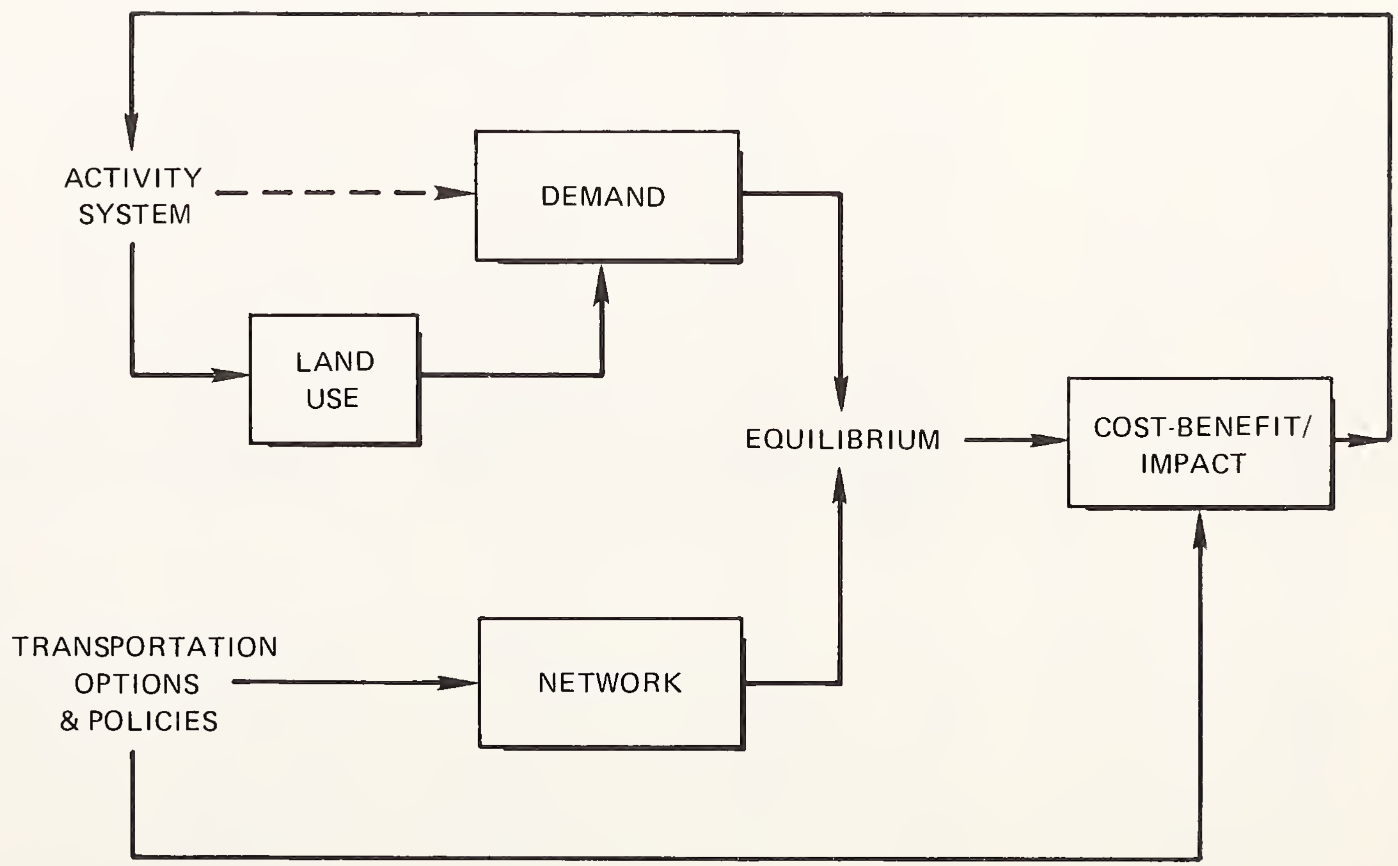

FIGURE 2: RELATIONSHIP BETWEEN DIFFERENT CLASSES OF MODELS

between origin-destination pairs. Typically, travel demand is expressed as a function of a number of socioeconomic and transportation level-of-service variables. The actual trip interchange between an O-D pair is therefore determined by the level of service and socioeconomic activities.

Demand models play two roles in UTP. First, demand estimation is prerequisite information in the planning of transportation "supply" alternatives for the target year. Second, an accurate estimate and judicious choice of demand functions is also crucial to the rigorous economic determination of cost-benefit/impact in a supply/demand framework (for example, the calculation of consumer surplus).

Categorization of Demand Models

There have been numerous insightful categorizations of demand models [e.g., see Ruiter (1972), Manheim (1972)]. To summarize, one or more of four labels are usually tagged onto a model:

- sequential vs. direct;
- aggregate vs. disaggregate.

A sequential approach to demand modeling refers to the series of steps commonly used in UTP—trip generation, trip distribution, and modal split—where the output of the previous step serves as input to the next step. A direct demand model, on the other hand, estimates in one step the travel demand between an O-D pair by a specific mode, using a simultaneous set of socioeconomic and transportation factors. Examples of such models are those by Baumol-Quandt (1966), McLynn (1967), and the early work of Charles River Associates (1967). The sequential approach, which has been packaged within the standard FHWA programs, is appealing to many practitioners since it breaks down the demand estimation procedure into controllable steps. Checks and adjustments can be made at each step to ensure that "reasonable" results are obtained. The direct approach, with its elasticity coefficients, is more amenable to economic analysis regarding cost-benefit/impact calculations (Harvey, 1972). It has the mathematical advantage of being a close-form demand formulation, relating demand to a number of explanatory

factors through elasticity coefficients. Yet this single step method gives rise to structural characteristics which are hard to control, sometimes resulting in unreasonable demand estimates.

Demand models, especially modal split models, can also be labeled aggregate or disaggregate. Aggregate models are usually equated with the prediction of demand on a zonal average basis. The standard UTP techniques are typical examples. Disaggregate models, which are often synonymously called behavioral, simulate travel decisions on a household or individual basis. Two steps are involved in the construction of a disaggregate model. First, a theoretical structure based on an intuitively appealing probabilistic statement is postulated. Second, the structural relationship is verified, or calibrated, in terms of statistical observations. The n-Dimensional Logit modal split model is an example.

Currently, the trend is to emphasize the disaggregate approach, for two reasons:

- The structural formulation of the disaggregate models can be judged and screened a priori regarding its behavioral validity.

- Working with data on individuals or households, rather than zonal averages, frees the data from ties to the urban zonal structure. In this way, it is possible to transfer calibrated results between urban areas.

Demand Modeling

The trip generation and distribution and modal split phases of UTP constitute the set of sequential demand models. (Generation and distribution have been referred to collectively as "trip estimation.") Trip generation is the step in which trip ends (productions, T_i, and attractions, T_j) are estimated from a number of socioeconomic factors. Trip distribution allocates these trip ends between zones and arrives at O-D trip interchanges, T_{ij}. The O-D trip table is then subject to modal split—e.g., between auto and transit—resulting in trips from i to j by mode m, T_{ijm}. There are practices in which modal split is performed at or after

the generation step, with distributions carried out on separate transit and highway networks. Such approaches are called "direct generation" and "trip end modal split," respectively. However, it is more logically consistent to follow the generation, distribution, mode split sequence, where distribution and mode split are computed on an integrated transit and highway network. This approach is known as "trip interchange modal split."

The sequential approach, as illustrated in Figure 3, is a series of steps to break down demands into "shares." Trip generation estimates the gross trip totals for productions, T_i, and attractions, T_j. Trip distribution decomposes these trip totals into "shares" of zonal interchanges, T_{ij}. Modal split, again, resolves the interchanges into their component modal shares, T_{ijm}, where the subscript m stands for the mode.

Figure 4 shows the trip ends, T_i's and T_j's, as row and column totals of a matrix. The interchanges, T_{ij}'s, are cells of a matrix, and the interchanges by mode represent different copies of the matrix.

Considerable care was exercised in selecting the models to be reviewed so that the sample would reflect the particular UTP procedures which have scored favorable application experience. Table 1 gives a comprehensive tabulation of demand models, listed in the order of historical development within each subcategory. Models on this list were examined and a few were selected for detailed review.

Comparison of the Reviewed Models

The models reviewed were chosen to cover the various categories of demand models. As Table 2 shows, the choices included one regression model for trip generation; two distribution models, Gravity and Intervening Opportunity; and four modal split models, two of the aggregate type (TRC and Pratt's), and two of the disaggregate type (Probit and Logit). The comparatively large number of modal split models considered reflects the amount of emphasis placed on this field by the profession at large.

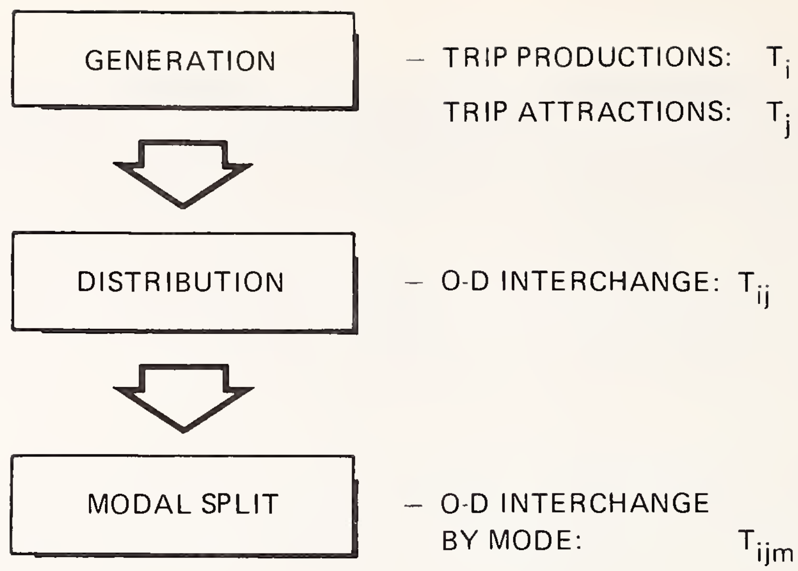

FIGURE 3: SEQUENTIAL APPROACH TO DEMAND MODELING

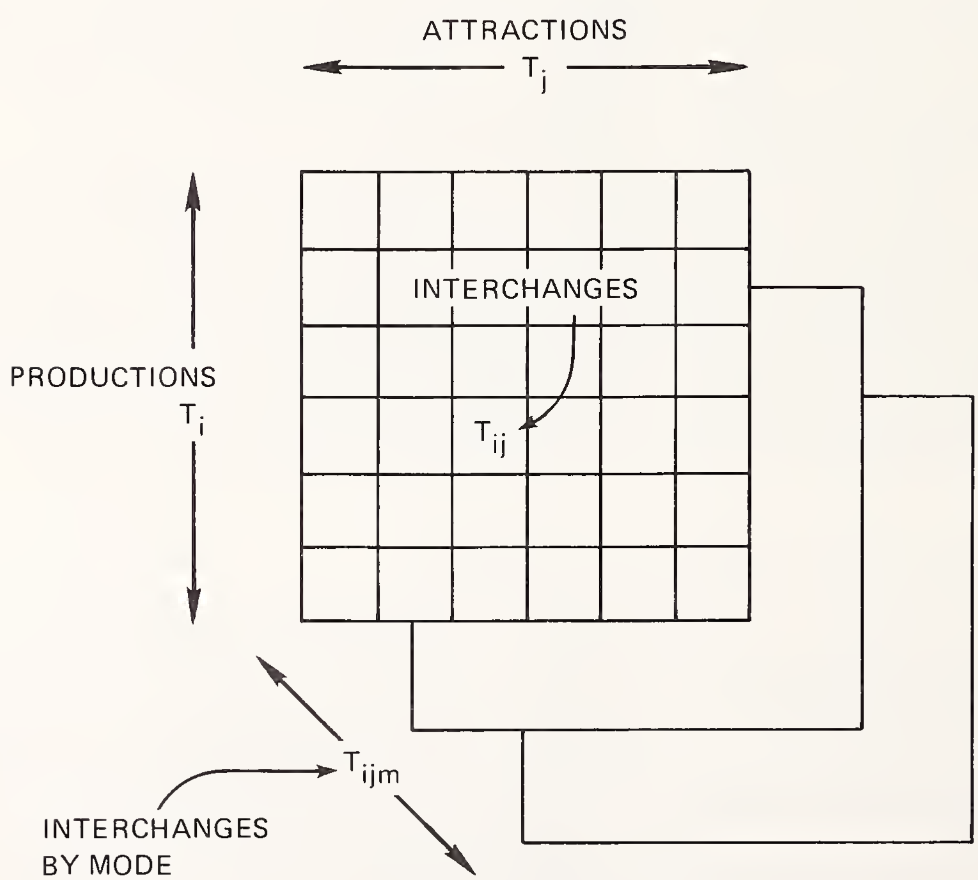

FIGURE 4: GRAPHICAL REPRESENTATION OF PRODUCTIONS, ATTRACTIONS, INTERCHANGES, AND MODES

TABLE 1

DEMAND MODELS CONSIDERED FOR REVIEW

Model	Reviewed?	Comments
DIRECT DEMAND		
Economic Demand Model	Yes	Good theoretical structure, but calibration has not been fully tested.
McLynn Model	No	Not fully tested in the urban context.
Baumol-Quandt Model	No	One of the few "abstract" mode models; good formulation, yet having calibration problems.
SEQUENTIAL		
Generation		
Trip Generation Regression Model	Yes	The most widely used trip generation technique.
Cross Classification Technique	No	Although computer programs exist in the FHWA package, the technique is still not fully tested.
Distribution		
Growth Factor Distribution Models: . Uniform Factor . Average Factor . Detroit . Fratar	No	Although simple to use, none of these models relate demand to explanatory factors. However, they have been widely used in the profession because of their simplicity.

TABLE 1 (CONT.)

Model	Reviewed?	Comments
Distribution (Cont.)		
Gravity Model	Yes	Convenient and widely used.
Intervening Opportunity Model	Yes	Probabilistic formulation; packaged as an FHWA program.
Modal Split		
Direct Generation; Trip End Modal Split Model	No	Although having obvious computational advantages, the approach is logically inconsistent and the modal split is not directly related to the level of service for each mode.
TRC Modal Split Model	Yes	One of the classic modal split models in the profession.
Twin City Modal Split Model	No	Although a regression approach is used, model structure is similar to the TRC model; present status of model unknown.
Warner Model	No	Experimental piece of work; outdated by now.
Pratt Marginal Utility Model	Yes	An appealing approach using the concept of marginal utility.
Lisco Probit Model	Yes	An approach similar to but more generalized than Pratt's model.
Stopher Logit Model	No	Only two mode, binary choice—a special case of the n-dimensional version.

TABLE 1 (CONT.)

Model	Reviewed?	Comments
Modal Split (Cont.)		
Wallace Psychometric Scaling Model	No	A model based on market research techniques; exploratory and not fully tested.
n-Dimensional Logit Model	Yes	Generalizing 2-mode model to n modes.
CRA Disaggregated Demand Model	No	A conceptually appealing approach to model demand as a sequence of decisions— mode choice, time of day choice, destination choice, trip frequency choice. Model structure bears resemblance to n-Dimensional Logit Model, which was reviewed.

Model	Type	Limitations
SEQUENTIAL DEMAND		
Trip Generation Model	Trip Estim - Generati	Balancing productions and attractions requires experience
Gravity Model	Trip Estim - Distribu	Have to accept an inherent assumption of travel pattern uniformity over all zones irrespective of socioeconomic characteristics, locations of zones in urban area, etc.
Intervening Opportunity Model	Trip Estim - Distribu	Calibration requires familiarity and experience with the model
TRC Modal Split	Modal Spli - Aggregat	Curve fitting by hand tedious to perform; only two modes at a time allowed
Pratt Marginal Utility Model	Modal Spli - Aggregat	Two modes at a time, unwieldy to use for multimodal case
Lisco Probit Model	Modal Spli - Disaggre	Only two modes allowed at a time
n-Dimensional Logit Model	Modal Spli - Disaggre	Maximum likelihood and simultaneous least square calibration techniques are not as commonly available off-the-shelf; also they require better familiarity with statistics.
DIRECT DEMAND		
Economic Demand Model	Direct dem model - aggregate	Demanding calibration procedures, both from the point of view of computational resources and sophistication of the user.

TABLE 2

COMPARISON OF DEMAND MODELS REVIEWED

Model	Type	Methodology	Resource Reqts.	Availaoility	Merits	Limitations
SEQUENTIAL DEMAND						
Trip Generation Model	Trip Estimation - Generation	Multiple linear regression (ordinary least square)	For medium size city (600-900 traffic zones), approx. 43 minutes of clock time is required per run on 370/155.	FHWA, UTPS or any statistical regression package	Simple in concept, program packages readily available	Balancing productions and attractions requires experience
Gravity Model	Trip Estimation - Distribution	Newton's law of gravity (manual calibration).	Half-hour per run on 370/155 with 894 zones and 5 trip purposes	FHWA battery of programs	Straightforward in concept and calibration procedure	Have to accept an inherent assumption of travel pattern uniformity over all zones irrespective of socioeconomic characteristics, locations of zones in urban area, etc.
Intervening Opportunity Model	Trip Estimation - Distribution	Probabilistic theory of intervening opportunities	For 900 zones and 5 trip purposes, each run requires about 1/2 hour on 370/155.	FHWA Programs	Probabalistic statement of trip distribution behaviorally appealing	Calibration requires familiarity and experience with the model
TRC Modal Split	Modal Split - Aggregate	Manual curve fitting	For the automated portion, 3 minutes 370/155 time for 60,000 interchanges	The methodology and manual technique available to public; automated portion proprietary to PMM&Co.	Field tested; manual technique easy to understand	Curve fitting by hand tedious to perform; only two modes at a time allowed
Pratt Marginal Utility Model	Modal Split - Aggregate	Either manual curve fitting or by regression	Manual calibration used in most studies with occasional use of computer routines. For the automated portion, 3 minutes of 370/165 time for each run, where there are 120,000 interchanges	The theory and manual technique available to general public; modal split, regression routines, etc., if used, are obtainable from statistical package such as UTPS	Field tested; graphic technique simple to use	Two modes at a time, unwieldy to use for multimodal case
Lisco Probit Model	Modal Split - Disaggregate	Either manual curve fitting or by regression	Approx. 1/2 minute per run for 8 indep. variables on 7094 (159 observations)	Multiple regression technique available in a number of statistical packages, also in FHWA, UTPS	Curve fitting through individual data points instead of using zonal averages; fewer data points required	Only two modes allowed at a time
n-Dimensional Logit Model	Modal Split - Disaggregate	Calibration by simultaneous least squares or maximum likelihood	Two minutes for 300 observations on 370/155	Theory available on literature calibration package proprietary to PMM&Co.	Stochastic, behavioral assumptions. Curve fitting through disaggregate data - fewer data points required. Convenient for multimodal analysis.	Maximum likelihood and simultaneous least square calibration techniques are not as commonly available off-the-shelf; also they require better familiarity with statistics.
DIRECT DEMAND						
Economic Demand Model	Direct demand model - aggregate	Multiple linear regression/quadratic programming	3.2-7.1 min. of CPU time per run on 360/50 for a quadratic program with an avg. size of 17 variables and 240 interchanges	Quadratic programming and multiple regression packages available on most machines	Based on sound economic theory—analytical forecasting and evaluation tool	Demanding calibration procedures, both from the point of view of computational resources and sophistication of the user.

Various structural methodologies have been employed in the demand models. One technique is common to all of them: statistical calibration. The following "statistical-fit" techniques have been employed, ranging from the most straightforward to the sophisticated:

- manual procedures - e.g., in calibrating the two distribution models and the TRC modal split model;

- ordinary least squares - e.g., in trip generation and in Pratt's and Lisco's modal split models;

- "simultaneous" least squares - e.g., in the calibration of the n-Dimensional Logit Model;

- maximum likelihood - e.g., in the Lisco and Logit behavioral/disaggregate models.

The maximum likelihood method employs an iterative procedure, resulting in a higher computational requirement than the other methods.

Most of the demand models were selected for review on the basis that the method and/or the associated computer programs are available to the public. The trip generation and distribution models are available in the FHWA battery of programs. The methodologies of the modal split models, except for some of the software developed "in-house" to an organization, belong to a body of knowledge open to everyone.

The reported resource requirements to operate these models are not excessive. The most time-consuming seems to be the Trip Generation Model, which requires 43 minutes of 370/155 "clock time" for an average urban area of 600 to 900 zones, including pre-processing data, estimating regression coefficients, and substituting the independent variables in the generation of trip ends. Some of the reported run times are highly qualified because of the heterogeneity of machine types, timing criteria, size of the problem, number of iterations, etc.

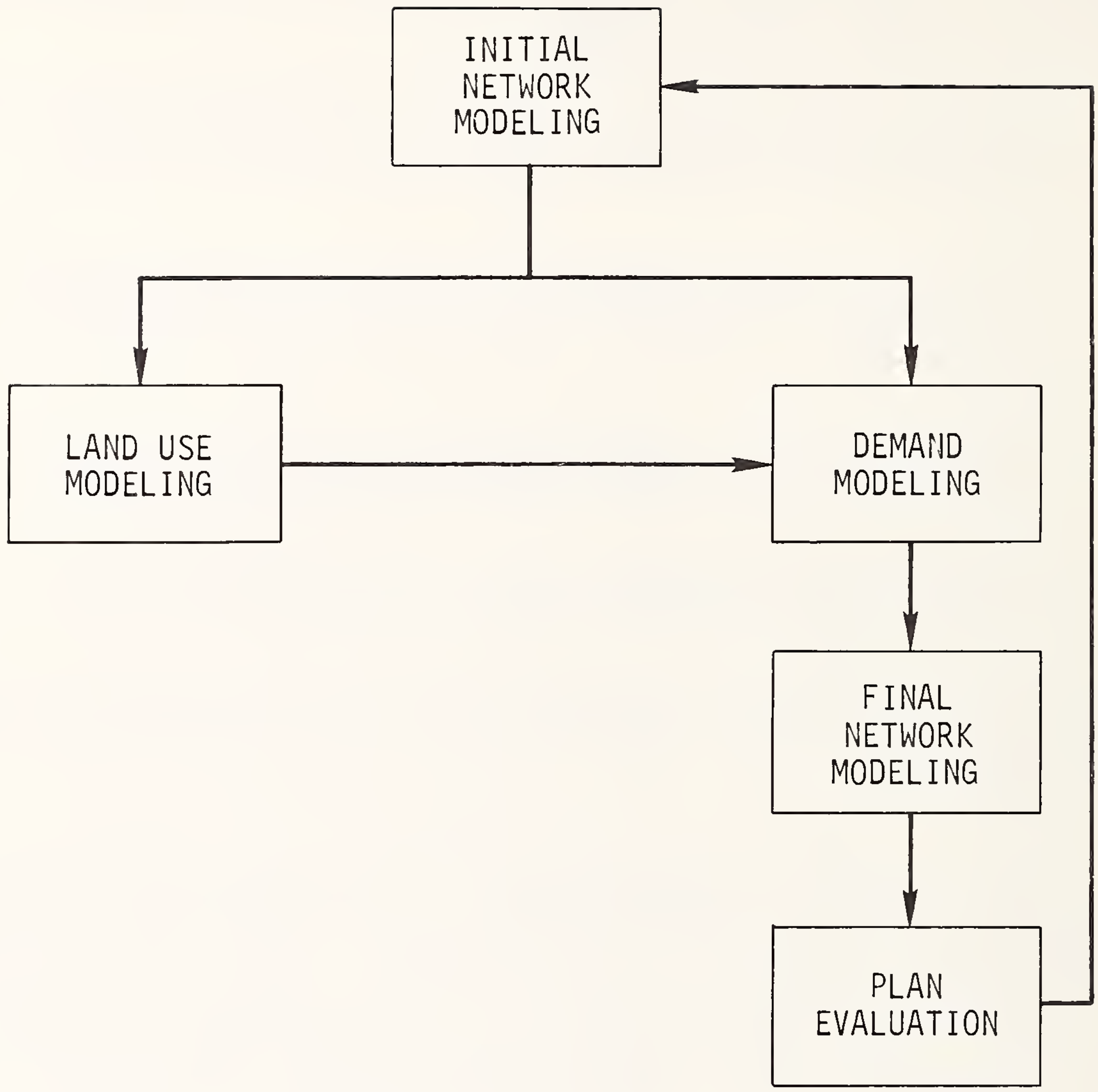

FIGURE 5: GENERAL ROLE OF NETWORK MODELS IN THE UTP PROCESS

The merits and limitations of each model are displayed in Table 2. Except for trip generation, there is more than one model to choose from in performing the same task. Of the two models recommended for trip distribution, the Gravity Model is the more widely used because of convenience. The four modal split models have been listed in increasing order of sophistication. The ranking also represents a decreasing order of convenience; that is, the models at the bottom of the table require more familiarity and skill to operate.

NETWORK MODELS

In a typical application of the urban transportation planning process, network models are exercised at two distinct points. These two points are quite separated from one another in the process, as can be seen in Figure 5. The first use of network models is in the development of travel impedance, derived from the transportation network, for input to land use allocation and demand modeling. The second use is to take the output from the demand modeling and to distribute the individual ij demands across the links that form paths through the transportation network. It is also true, unfortunately, that the calendar time and cost separating these two points are so great as to effectively prevent, in most cases, checking and cycling back through the network, demand, and land use blocks of the process until a condition of equilibrium is approached. It is this potential lack of equilibrium attainment that marks the weakest theoretical portion of the UTP process.

All of the network models reviewed share one point in common: they all require that detailed transportation networks be coded for computer representation. The amount of detail required is controlled by the user, but experience has shown that the quest for "better answers" leads to the development of quite detailed, costly, and time-consuming networks. A rough rule of thumb is that approximately one man-day per 50 to 75 links in the network is required for the design, mapping, coding, and calibrating of a network.

The types of data required to be coded to represent the highway network are somewhat different from, and in many ways less complicated than, the data and coding

procedures necessary for the representation of a transit network. Highway maps in everyday use display a geographic or spatial network of routes (links) and towns (nodes). In transit, there is concern with the temporal as well as the spatial dimension; i.e., in making a decision to render service between two points A and B, a decision also has to be made concerning when and how frequently to dispatch the vehicles. Therefore, the transit network must be concerned with a time axis as well as the spatial axes. In addition, the transit network has the attribute of type of vehicle. These three attributes together serve to specify routing and scheduling.

Categorization of Network Models

The operational network models that were selected for review fall into one of two general classes:

- single minimum impedance path;
- multipath.

There has, however, been an attempt to move from the first class toward the second through the use of capacity-restraint formulations during demand loading. The existing operational minimum path network programs, even when coupled with capacity-restraint programs, assign demand to a single path in each iteration and then to different paths during different iterations.

In general, all network models reviewed contain the following four components, whether embodied in a single step in a single program or as a combination of steps in a single program:

- Network Builder - program or procedure to process the coded link data containing attributes of the real-world physical transportation system into a form that is computer-processable by the other network programs. The attributes can be for any time period for which the user wishes to develop a computer-processable network description.

- Path Builder - program or procedure to process the computer representation of the transportation network in order to find a path or paths through the network from each zone "i" to each and every (accessible) zone "j," based upon a specified criterion for selecting one of the coded attributes. Attributes used may be time, distance, cost, or in some cases, a user-specified combination of some or all of the above. All single path models build their paths based upon minimizing the selected attribute. A multipath model builds its paths based upon the selection of the path that minimizes the selected attribute and the next "x" worse paths; i.e., paths slightly longer than the minimum path. It should be noted that a multipath model is behaviorally more appealing than a single-path model.

- Path Impedance Skimmer - program or procedure to process the computer representation of the transportation network and create the summed (skimmed) value of a specific attribute taken from all links that form the path for each ij pair (or, in the case of a multipath model, the weighted average over the multiple paths). The summed values of the attributes are then used as necessary input to the various land use allocation, demand, and/or cost-benefit/impact models described elsewhere in this report.

- Network Loader - program or procedure to process the computer representation of the transportation network, the ij set of paths, and the ij matrix of travel demand (the trip table) in such a manner as to load each link in a path(s) between "i" and "j" with the travel demand. The result, after all ij pairs have been processed, is the total volume using each link in the transportation network. The network attributes can then be updated, using specified capacity-restraint relationships,

TABLE 3

NETWORK MODELS CONSIDERED FOR REVIEW

Model	Mode Specific?	Reviewed?	Comments
SINGLE PATH			
FHWA Network Programs	No	Yes	Theoretical structure poor, but usefulness is attested to by its use.
DCO/TRANPLAN Network Programs	Separate by mode	Yes	Same as FHWA.
SNAP	Separate by mode	Yes	Useful for "quick-and-dirty" sketch planning type problem.
UTPS Network Programs	Transit	Yes	Specifically developed for transit planning. Presently under intensive research and development.
MULTIPATH THROUGH CAPACITY RESTRAINT			
FHWA Network Programs	Highway	Yes	Expensive to use.
DCO/TRANPLAN Network Programs	Highway	Yes	Expensive to use, but incremental loading approach is somewhat more appealing than FHWA approach.
SNAP	Highway	Yes	Interesting approach to updating network after restraint applied and the use of a network-dictated incremental assignment of demand.
DODOTRANS	No	Yes	An "equilibrium" model. Capacity restraint applied by loading increments of ij demand on alternative paths depending on the network loading. Operational only in the general sense.
CATS	Highway	No	Has not been used outside of Chicago.
TRC (Toronto)	Highway	No	Long computer running times. Couples trip distribution with assignment. Not used elsewhere.
MULTIPATH			
Dial Stochastic Assignment Model	No	Yes	One version of Dial's algorithm is implemented. Some problems in use. Need for further research into path diversion (θ value).

to their values under the loaded condition. If equilibrium has been attained, the attribute values should closely approximate the initially assumed values.

Network Modeling

The total number of network models considered for review is presented in Table 3. After examining each model for operational status, six models were selected for a complete formal review:

- FHWA Network Programs
- DCO/TRANPLAN Network Programs
- SNAP
- UTPS Network Programs
- DODOTRANS
- Dial Stochastic Assignment Model

The first three models are reviewed here in their single path, all-or-nothing form. However, they could be used for multiple path traffic assignment with capacity restraint, if desired.

FHWA Network Programs

The underlying assumption of the FHWA network model is that the traveling public is able to discern accurately which path through the transportation network is the shortest (based upon some attribute or combination of attributes, such as time or time/distance) and that this shortest path will always be used. The theory relies on the selection of different routings in different iterations for the same ij pair to simulate the multiple routings the traveling public really uses.

The actual algorithm, a modification of the Moore algorithm, widely used in the selection of minimum impedance

paths through a network, can build either "trees" or "vines." The difference between the two is that in the "vines" option, a node can be entered more than once on any path. The consequence is considerably longer computer running time. The vines option, however, builds more realistic paths in a network with numerous freeway interchanges.

The user has the choice of selecting either the standard FHWA capacity-restraint function or a set of up to 10 self-produced functions. If a user-produced set of functions is used, specific ones can be applied to particular classes of links.

<u>DCO/TRANPLAN Network Programs</u>

The DCO/TRANPLAN network model is a proprietary package developed jointly by DeLeuw, Cather & Company and Control Data Corporation (CDC). This set of models is an outgrowth of the CDC 3600 TRANPLAN and the HUDTRAN programs. The programs were written for the CDC 3600 computer and must be run at CDC data centers.

The underlying assumption of this model, like the FHWA network model, is that the traveling public does attempt successfully to minimize the overall amount of travel in the transportation system. As such, this model suffers from the same theoretical problems as the FHWA network model.

The capacity-restraint highway assignment algorithm does allow for the assignment of demand incrementally, but the increments are set by the user externally to the program. This requires that the user be experienced with his own network and trip table in order to take the fullest advantage of this option.

The user can specify either his own capacity-restraint functions, or use the same standard capacity-restraint function developed by the FHWA.

In many if not most respects, the DCO/TRANPLAN network model simply represents a somewhat streamlined version, with better interfacing, of the same programs as exist separately in the FHWA and UTPS batteries. As such, they represent no

new theory, but are generally easier to use if a CDC data center or computer terminal is available.

SRI Network Analysis Programs

The network modeling portion of SNAP is a proprietary package developed by Stanford Research Institute (SRI) and implemented on the CDC 6400 computer. Its present usefulness is for gross networks in the sketch planning framework.

The basic assumption underlying SNAP is again that the use of minimum time paths, created through use of the minimum path algorithm of the Road Research Laboratory in Great Britain, is sufficient for modeling travel behavior, especially when modified through use of a capacity-restraint procedure.

The iterative capacity-restraint procedure makes use of an incremental loading procedure determined by network capacity. The size of the loading increment is determined through use of a "critical link method" of adjusting travel times on links as they are loaded. In subsequent iterations, the links that are loaded to a user-specified portion of their capacity are removed from the network.

UMTA Transportation Planning System

The UMTA Transportation Planning System (UTPS) network model that is now presently available is essentially the Housing and Urban Development (HUD) Transit Planning Package converted to the IBM 360 system. The model is aimed primarily at the transit planning field.

As a portion of the DOT/UMTA New Systems Requirements Analysis Program (NSRAP), extensive research is now underway to expand upon the modeling power of the UTPS. Of particular interest to all in the transportation planning profession are the attempts to develop new models with extremely short "turnaround" time. Toward this aim, methods for conducting aggregate, instead of detailed, modeling that will place less dependence on massive data bases and coded networks, and will in general cut down on resource costs, are now being developed. As part of these techniques, emphasis

is being placed on interactive graphics using graphic terminals. This approach now promises to be a far more effective means of interfacing the analyst and the model than do the batch-processing systems.

DODOTRANS

DODOTRANS, which stands for Decision Oriented Data Organizer TRansportation ANalysis System, is a total computer software package developed at the Massachusetts Institute of Technology. DODOTRANS was developed in an academic environment to serve as a "breadboard" (experimental environment) on which new models and approaches could be tested. Through its English-like commands, DODOTRANS allows the user to interact with the computer in common transportation terms, rather than being forced into the technicalities of programming languages.

The network model is included in the general section of DODOTRANS known as prediction models. The network model performs an "incremental" traffic assignment to approximate network equilibrium. The algorithm employed consists of five basic stages:

- random selection of an origin-destination (ij) pair;
- determination of the minimum time path between i and j, which constitutes the travel cost between the ij pair;
- determination of the potential demand between i and j by use of a demand curve;
- addition of the increment of potential demand to the minimum time path; and
- determination of updated travel times on the links in the minimum time path that are due to the assigned demand, through use of a "volume/delay" curve. Up to fourteen volume/delay curves can be used.

These five steps are repeated until, for each ij pair, the assigned demand (volume) first exceeds the potential demand as determined from the demand curves.

The performance of the traffic assignment is the major portion of a complete set of computations using DODOTRANS. The actual computer run times for an incremental traffic assignment depend on a number of factors. The more critical factors are found to be:

- the number of analysis districts (traffic zones); and
- the shape of the demand and volume/delay curves (non-linearity of the curves means large increases in computer time).

Average computer time for a network of 40 districts is about 2 minutes of central processing unit (CPU) time on an IBM 360/40.

Dial Stochastic Assignment Model

The only truly multipath traffic assignment model that is in an operational state today is an algorithm developed by Dr. Robert B. Dial while at Alan M. Voorhees and Associates, Inc., under U.S. Department of Transportation Contract FH-11-6972. This algorithm, named the Parallel Probabilistic Multipath Assignment, is presently implemented in both the FHWA battery of programs and the DCO/TRANPLAN package under the name of Program STOCH.

The reason for the development of Program STOCH, and the underlying theory of the model, was to more correctly model the nondeterministic choice function of the traveling public in a manner that is usable (i.e., economically feasible). It is, in fact, this necessity of economic feasibility that has led to the implementation of the Parallel Probabilistic Multipath Assignment algorithm instead of another, somewhat more theoretically appealing, algorithm also proposed by Dr. Dial.

The Program STOCH formulation recognizes that the basic assumption underlying the assignment of demand only to the minimum path between a given "i" and "j" contradicts actual

travel behavior. There are five common-sense functional specifications on which the model is based:

- The model should give all "reasonable" paths between i and j a non-zero probability of use. Conversely, all "unreasonable" paths should be given a zero probability of use.

- All reasonable paths of equal length should have an equal probability of use.

- Where there are two or more reasonable paths of unequal length, the shorter should have the higher probability of use.

- The user should have some control over the path diversion probabilities.

- The explicit enumeration of paths should not be necessary.

Central to the model theory is a working definition of "reasonable path." Dial defines a reasonable path as one that is efficient and further defines an efficient path as one that does not backtrack on itself. He then sets the working condition for path efficiency to be as follows:

> An efficient path between zones O and D must be composed only of links possessing the property that the initial node i of the link is closer to the origin node O than is the final node j of the link.

This working definition of efficient path is considerably less discriminating than the corresponding definition for the second algorithm proposed by Dial. However, under this definition a graph of all efficient paths from a common origin zone O may be described in a single pass. This graph, termed a "bush rooted at O" by Dial, contains all of the efficient paths from O to all zone destinations D and, in the assignment pass, all demand from O can be assigned simultaneously.

The actual amount of diversion allowed in the choice of paths is governed in the calculation of path likelihood (probability) by the parameter θ. As the value of θ varies from zero to infinity, the probability of using a particular path which is Δt longer than the shortest path is directly proportional to the quantity exp $-(\theta \Delta t)$. Therefore, as the value of θ increases, the likelihood that the links forming the minimum path will be used is increased. When the value of θ is zero, all efficient paths are considered to be equally likely to be used. On the other hand, when θ is large the result is that only links on the multiple shortest paths (if more than one shortest path exists) have any likelihood of being used. This situation results in the equivalent of an all-or-nothing assignment that appropriately considers parallel routings.

At this point in time, the most appropriate value of θ to use (if, indeed, a single value is appropriate) is not known. This is an area which will require additional research before Program STOCH can reach its full potential value.

Comparison of Network Models

The six network models reviewed fall into two general categories based upon their path selection routines: single path and multipath. Through the use of capacity-restraint relationships in the demand loading, the highway versions of the single path models attempt to account for the multiplicity of path choices displayed by the traveling public by allowing for the possibility of path change between iterations. The success of this attempt is governed greatly by the "goodness" of the capacity-restraint relationships and the initial design of and attributes coded for the network itself.

The merits and limitations of each of the network models are presented in Table 4. While the information contained in this table can assist in the selection of a model, the final choice between models must be governed by the particular circumstances that exist at the moment of selection. For example, the size of the application, the purpose of the application (sketch versus detailed planning), the familiarity of the staff with one set of programs, the appropriateness

TABLE 4

COMPARISON OF NETWORK MODELS REVIEWED

Model	Theoretical Base	Availability	Resource Requirements	Merits	Limitations
FHWA Network Programs	Single path with or without capacity restraint	FHWA battery of programs	Dependent on network sizes and computer configuration, but ranges from ten minutes to three hours of computer time.	Best known and most widely tested. Readily available.	Expensive for large networks and for capacity restraint. Theory only partly satisfying.
DCO/TRANPLAN Network Programs	Single path with or without capacity restraint	CDC Data Centers and CYBERNET System	Essentially the same as FHWA	Program control very simplified. All programs, both highway and transit, together in the same package.	Expensive. Theory only partly satisfying. Proprietary.
SNAP	Single path with or without capacity restraint	Proprietary to SRI and only implemented for the CDC 6400	Five to ten minutes of computer time for the very limited applications now possible.	Network programs tied together in a single package that encompasses the full range of transportation planning requirements.	Useful only for sketch planning-type applications (100 zones, 500 nodes, 1,000 one-way links).
UTPS Network Programs	Single path	UMTA Transportation Planning System	Dependent on network size and computer configuration.	Designed specifically for transit planning. Now in the process of being greatly expanded.	Theory only partly satisfying. Expensive to use.
DODOTRANS	Single path with capacity restraint	Through MIT or Pacific International Computing Corporation.	Dependent on many factors, but not critically a. Network Size b. Demand & Volume/ Delay curve shape On 370/155 average computer time is two minutes for 40-zone network.	Represents one of the state-of-the-art models; ties demand to network congestion to approach network equilibrium.	Basically a teaching tool. Not presently suited to large-scale, production studies. Major limitation is a maximum of 8,191 one-way links. Very expensive.
Program STOCH	Multipath	FHWA battery of programs; DCO/TRANPLAN	Dependent on network size. Ranges from one minute (100 zones) to 40 minutes (700 zones). Run times approximate 1.5 times an all-or-nothing assignment.	Theoretically the most pleasing.	Rather untested. Need to further calibrate the diversion parameter θ. Does not, by itself, incorporate network capacity restraints.

(and staff willingness) of exploring somewhat unknown ground, and the type of computer available all are practical restraints on the final selection made.

COST-BENEFIT/IMPACT MODELS

Cost-Benefit/Impact Measures

Cost-benefit/impact or transportation performance measures are the guidelines against which the characteristics of alternative networks can be measured and their respective abilities to satisfy community goals and objectives can be determined. Regardless of whether the goals and objectives are common to all communities or peculiar to a specific community, users, the operator, or industry, the evaluation criteria fall into three classes:

- Costable: criteria whose nature allows a definite cost figure to be derived for them, such as engineering, right-of-way, construction, and user costs, demand or usage, etc.

- Quantifiable: criteria for which a definite cost figure cannot be ascertained but for which some type of cardinal measure can be determined, such as the number of displaced families and the amount of land accessible for different uses.

- Nonquantifiable (qualitative): criteria that can neither be costed nor cardinally measured at this time but that can be described and perhaps compared or ordinally measured, such as social, recreational, and aesthetic values.

The cost-benefit measure development should include the means for:

- assessing, measuring, and valuing the effects of transportation system changes on riders, the public, the system operator, and the industry;

- estimating the system costs of transportation changes (as appropriate); and
- relating transportation changes to higher level goals and to an overall framework for decision-making.

The cost-benefit/impact framework specifically incorporates the means for measuring the following:

- system usage (volumes): links and stations;
- system data: revenue, operating costs, vehicle requirements, and vehicle data;
- travel service: travel times and costs, transfers, accessibility, and mobility;
- trip characteristics;
- traveler characteristics;
- safety and public security;
- changes in auto traffic congestion;
- effects on land values;
- noise;
- pollution;
- housing and business relocation;
- community disruption; and
- development effects.

In this framework the impact measures estimate the degree to which transportation systems attain certain urban goals. The specific measures relate to four interest groups:

- rider;
- public;

. operator; and

. industry.

The rider and public groups are further disaggregated into subgroups. For example, the rider group would be disaggregated by socioeconomic class and, in particular, according to handicapped, elderly, and others with immobile status. A typical matrix of groups and performance measures is constructed as shown in Figure 6.

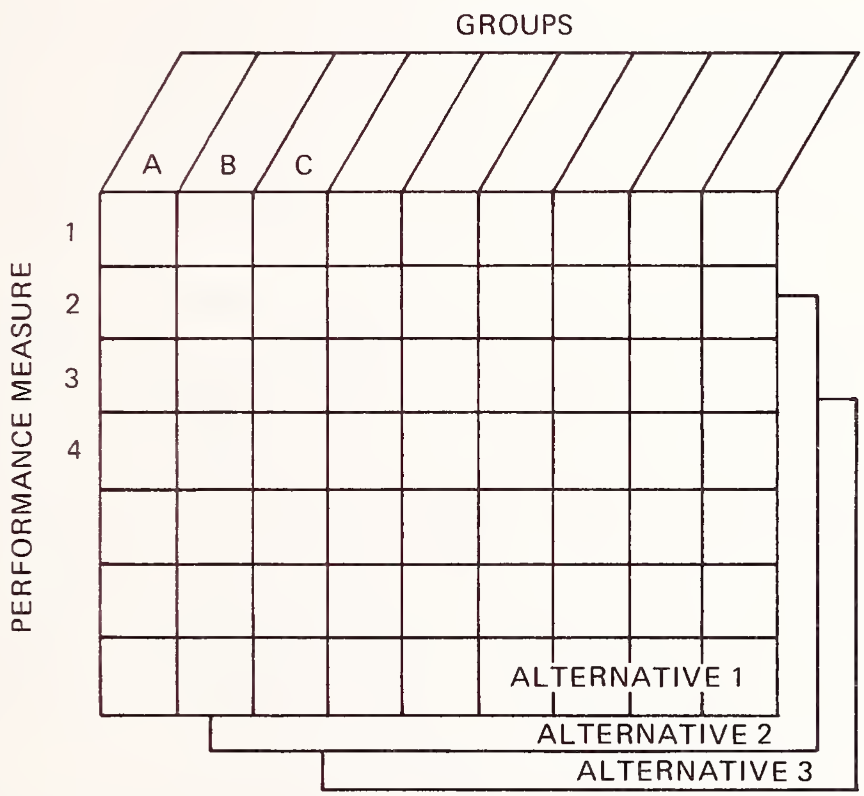

FIGURE 6: IMPACT INCIDENCE MATRIX

Developing the matrix entails a four-step process, as described below:

- Specify the groups by which the effects will be stratified.
- Specify the impact measures that will be used to estimate the achievement of goals and objectives.

- Develop measurement techniques to calculate the measures as they impact on the groups.

- Derive values that will weigh the measures (as appropriate).

An example of this developmental process is shown in Figure 7.

Cost-Benefit/Impact Modeling

Few cost-benefit models are available that are (1) fully programmed, (2) more sophisticated than simple compound interest equation manipulators, and (3) sufficiently general purpose with regard to transportation system technologies and applications to be able to be used in new urban planning programs without substantial reprogramming.

A cost-benefit model should be more than an accounting tool with compound interest formulas. It should also deal to some degree with generating the items of benefit and cost that are to be included. Certain items of benefit—both traveler benefit and community benefit—are general impacts that can be programmed without having to treat each technology and application as a special case. However, this is not true for cost models, which provide estimates of capital and operating costs of transportation systems. Here, technologies are so different from one another that special models must be built for each.

To construct models of both traveler and community benefits, it is necessary to deal with data generated by demand and network models. Thus, one concludes that if a cost-benefit model were not integrated with other models, it would still require data output from demand and network models. To treat cost-benefit analysis more adequately than current models do, substantial restructuring of the demand and network models will be needed in order to obtain pertinent data.

Table 5 presents a listing of some cost-benefit models that have been used to evaluate transportation systems. The three operational cost-benefit/impact models, which were selected for detailed review, each is a part of an integrated

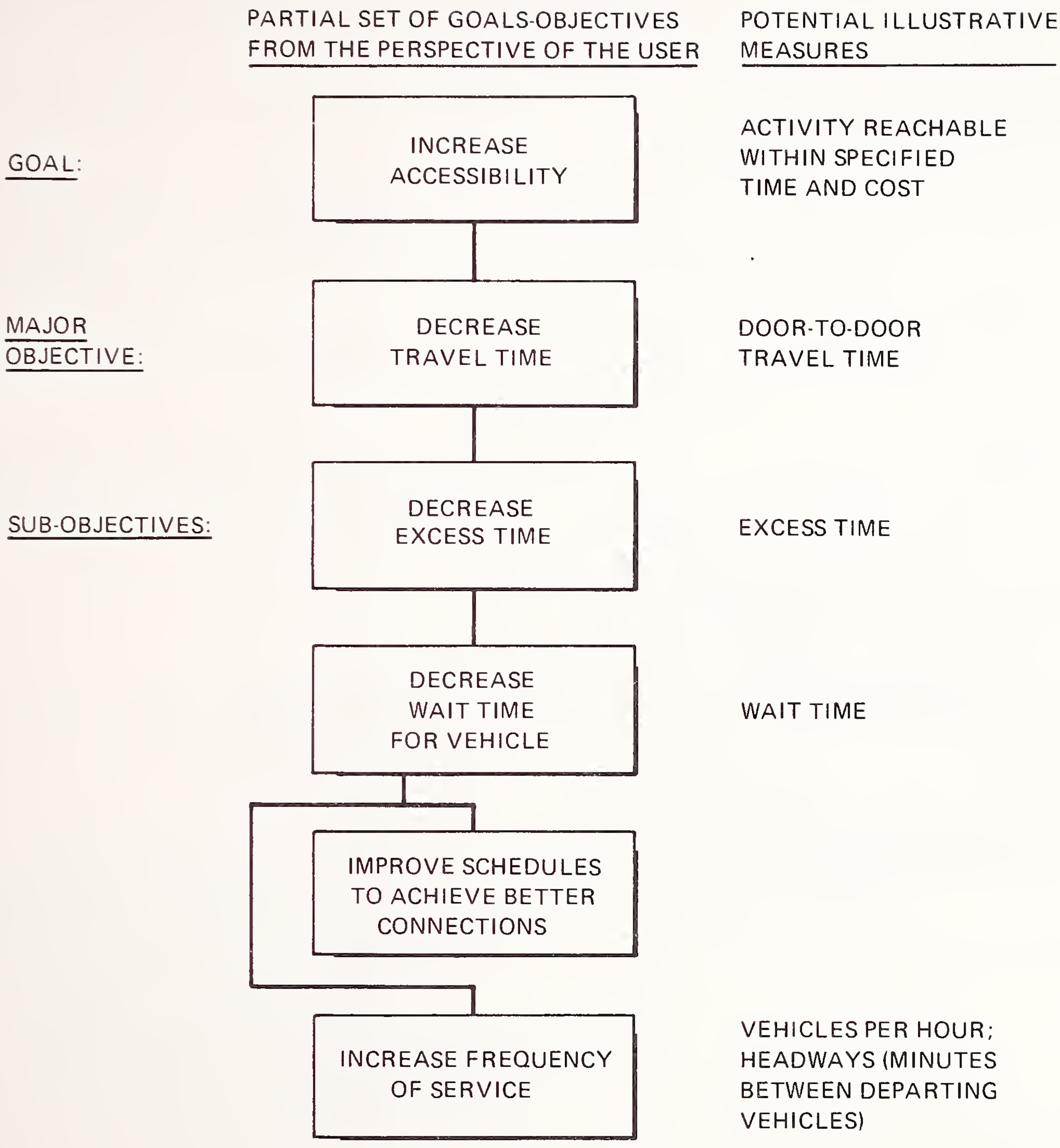

FIGURE 7: INTERRELATIONSHIP OF GOALS, OBJECTIVES, AND MEASURES

TABLE 5

COST-BENEFIT/IMPACT MODELS CONSIDERED FOR REVIEW

Model	Reviewed?	Comments
OPERATIONAL MODELS		
DODOTRANS	Yes	A computer software package developed at Massachusetts Institute of Technology.
TRANS	Yes	A computer software package developed by U.S. Department of Transportation.
SNAP	Yes	A network/cost-benefit computer package developed by Stanford Research Institute.
NONOPERATIONAL MODELS		
TRW Evaluation Model	No	Development work on a "stand alone" evaluation model is not completed.
TSC Dual Mode Cost-Benefit Model	No	This is a proprietary "stand alone" evaluation model that was developed and applied by TSC in "in-house" computer studies of alternative dual mode systems. Documentation and model results are not available at the date of this report.
UMTA-NSRAP Transportation System Evaluation Indicators Study	No	This is a report on the review and analysis of an extensive list of impact measures or performance indicators. No software package was developed.

TABLE 5 (CONT.)

Model	Reviewed?	Comments
NONOPERATIONAL MODELS (CONT.)		
MIT Technology Community Value Study	No	This was a review and analysis study. No software was developed.
Air Pollution Study for Environmental Protection Agency	No	This was a report prepared by Alan M. Voorhees and Associates, Inc., on air pollution measurement techniques. No software was developed.
Northeast Corridor Models	No	Several cost-benefit/impact and socioeconomic forecast models were developed for the Northeast Corridor Project for evaluation of Northeast Corridor intercity transportation systems and were made operational by the National Bureau of Standards. The models are not suitable for evaluating urban systems, since the cost models are specific to intercity transportation systems.

transportation planning software package. These models internally generate demand and network assignment inputs to the evaluation phase. Each model is briefly described below.

DODOTRANS

DODOTRANS stands for Decision Oriented Data Organizer TRansportation ANalysis System and represents one of the first efforts to integrate a number of the state-of-the-art transportation planning models and file manipulation routines. It is a useful tool to gain insight into prototypical network "equilibrium" problems with emphasis on policy-making and evaluation methodologies. A large number of models and data processing routines have been included in the package. There are prediction models, including a network model which performs incremental assignment; a resource requirement model which estimates costs; a demand model which can assume a mode-abstract direct demand formulation; and a demand shift model for very simple growth calculations. There are also evaluation models, which include a set of straightforward arithmetic and summation operations to convert outputs of the prediction models into various costable cost-benefit and impact measures. Separate impact files are produced for user, operator, and government (community) groups, including the functional impacts of population, income and accessibility changes. DODOTRANS, through its English-like commands, allows users to communicate with the computer in common terms of the transportation profession, rather than the technicalities of programming languages. An urban transportation network (highway and transit) with up to 8,191 one-way links can be analyzed.

TRANS

TRANS, which stands for Transportation Resource Allocation Study, is an operational computer software package developed by DOT. It is a policy planning tool geared toward the federal and state level transportation improvement programs involving multimodal transportation systems. The TRANS computer package incorporates, first, a routine to input alternative levels of transportation facility investment, where each modal mix constitutes a target year plan (expressed in terms of road mileage and vehicle miles instead of a fully coded network).

Second, the target year demand is projected, employing a family of relationships which forecast trip miles by purpose, time of day, and mode (direction of travel, facility type, and submodes for transit).

Third, the projected travel demand is distributed to the transportation system, outputting specific system performance measures expressed in dollar costs for private vehicles (travel time, vehicle running, accident, parking, and gas tax costs), and for public transportation (travel time costs and fare). Other transportation costs such as direct capital, operating and maintenance costs, and other quantifiable measures on fatalities, dislocation of households and businesses, and air pollution costs are produced.

Fourth, an economic analysis routine employs an economic efficiency concept to compute measures of consumer surplus (difference between total value or prices which all travelers are willing to pay and total transportation costs). The non-costable but quantifiable impacts are formulated as constraints that must be met. There are three versions of the model: urban, small urban, and rural. A high level of aggregation is used, and the analysis performed pertains to an average city in a given population category. TRANS, as a sketch planning tool, is a macro model and is not a substitute for the micro models such as DODOTRANS and SNAP. The package is very cost-effective, requiring about 40 minutes on an IBM 360 Model 65 to analyze 300 urban regions.

SNAP

The SRI Network Analysis Program was designed to be a highly flexible analytic procedure that could be applied to a wide range of urban person and goods movement transportation problems in large and small cities. The computer package does not incorporate new theories of traffic estimation, since it consists of the basic trip generation, trip distribution, modal split, and network assignment routines. However, the package has several extensions to permit the evaluation of both person and goods movements in urban and intercity areas. Standard inputs include system networks, cost parameters, accident parameters, and air and noise pollution data. Evaluation data outputs include traveler time and cost summaries; safety measures; trip time distributions;

comfort and convenience measures; accessibilities; community impacts (air and noise pollution); and system capital, operating, and maintenance costs. The program has some limitations—the maximum size problem can contain only 100 zones, 500 nodes and 1,000 one-way links. The program package is proprietary to SRI, and application costs are about $100 or about 20 minutes' computer time on a CDC 6400.

Comparison of Cost-Benefit/Impact Models

The three models reviewed fall into two classes: macro level analysis (TRANS) and micro level analysis (DODOTRANS and SNAP). All packages are reasonably cost-effective to apply. They all integrate the demand estimation, network assignment, and evaluation routines into a single computer program package. All three packages attempt to distinguish between costable and other quantifiable data and the different levels of impact groups (user, community, operator). TRANS attempts to produce household and business relocation impacts. Both SNAP and TRANS produce measures of environmental impacts such as noise and air pollution. None of the models attempts to measure non-quantifiable impacts that concern social and community values. These impacts must be exogenously specified by the user of the program packages. Table 6 compares the attributes of each model.

LAND USE MODELS

The models discussed in this section are designed to provide projections of the future small-area distribution of land use and related urban activity for use as input to the transportation planning process. Particular emphasis is placed on those models which may be considered to be currently "operational." A lesser degree of attention is directed toward models whose conceptual or theoretical structure makes them appealing but which have yet to be proven viable in an operational context.

Model		Limitations
DODOTRAN	- - i-	Limited networks up to 8,191 one-way links. Limited application by MIT and MBTA.
TRANS	. .	Does not use networks but macro level inputs. Analysis is for average or standard city in population category.
SNAP	. on	Maximum size 100 zones, 500 nodes, 1,000 one-way links. Proprietary Limited Documentation.

TABLE 6

COMPARISON OF COST-BENEFIT IMPACT MODELS REVIEWED

Model	Type	Methodology	Resource Requirements	Availability	Merits	Limitations
DODOTRANS	Micro Analysis; Network/Cost-Benefit Model	Regression fitting of demand curves incorporated in software.	Minimum configuration: IBM 360/40 with 128K, two 2311 disk drives. Running time on 370/155 is approximately two minutes for the traffic assignment on 40 districts.	Developed in University environment. Available from MIT, with limited demonstration, and from Pacific International Computing Corporation.	English-language commands. Field tested by Massachusetts Bay Transportation Authority (MBTA), Boston. Network Supply equilibrium model.	Limited networks up to 8,191 one-way links. Limited application by MIT and MBTA.
TRANS	Macro Analysis; Cost-Benefit Model	User input of demand or apply standard city demand curves.	IBM 360/65 with 220K. Running time is 40 minutes for 300 cities.	Limited availability from DOT for special applications.	Good documentation. Cost-effective to use. Field tested.	Does not use networks but macro level inputs. Analysis is for average or standard city in population category.
SNAP	Micro Analysis; Network/Cost-Benefit Model	No calibration routines. User must use own library routines.	CDC 6400. Running time is 20 minutes.	Proprietary to SRI.	Integrated package. Cost-effective. Extensive evaluation reports. Field tested.	Maximum size 100 zones, 500 nodes, 1,000 one-way links. Proprietary Limited Documentation.

Five models were singled out for formal review. These are:

- PLUM - The Projective Land Use Model, developed by Dr. William Goldner, Institute of Traffic and Transportation Engineering, University of California, Berkeley;

- USM - The Urban Systems Model, developed by Alan M. Voorhees and Associates, Westgate Research Park, McLean, Virginia;

- The EMPIRIC Activity Allocation Model, developed by Peat, Marwick, Mitchell & Co., Washington, D.C.;

- The Accessibility-Opportunity Model, developed by the New York State Department of Transportation; and

- UPM - The Urban Performance Model, developed by PRC Systems Sciences Company, McLean, Virginia.

The selection of these five models is somewhat arbitrary. The first four are truly "operational" in the sense that they have each been applied successfully in at least one, and in a number of cases, in several different metropolitan areas. The last model is more developmental in nature, although it too has been subjected to extensive empirical analysis and testing. It is included here primarily because of its strong conceptual relevance to transportation planning.

A large number of other models were also considered for inclusion within the list. These include:

- MLUT - A Model of Land Use and Transportation, developed by Creighton-Hamburg, Inc., Washington, D.C.;

- An Urban-Regional Model of Small-Area Change for Southeastern Michigan, developed by CONSAD Research Corporation for the Transportation and Land Use Study, Southeastern Michigan Council of Governments, Detroit, Michigan;

- DVRPC Activities Allocation Model, developed by the Delaware Valley Regional Planning Commission, Philadelphia, Pennsylvania; and

- TOMM - The Time Oriented Metropolitan Model, developed by CONSAD Research Corporation for the Community Renewal Program, Department of City Planning, Pittsburgh, Pennsylvania.

They were not singled out for more detailed discussion either because they have not been made fully operational in a general sense, or because they are still in a developmental phase.

A selected bibliography of pertinent reference materials, including all those used as source materials for this report, is included in Appendix E.

Role of Land Use Models in Transportation Planning

All of the models discussed in this section perform at least two major functions:

- They project the future small-area distribution of land use and related activity within a metropolitan area in a format appropriate for use as input to trip generation and related transportation planning modeling activities.

- They provide a means for estimating the probable impact of alternative future transportation planning policy decisions on the subsequent distribution of regional activity.

All of the models belong to a family referred to generically as "activity-allocation" formulations. That is, they are designed to allocate previously determined regionwide totals of "activity" among a set of smaller subregions or districts for each of a series of future points in time. "Activities" are defined variously within the several models as classified counts of population, employment, and land use. Population estimates are typically expressed either as simple, small-area population or household counts, or in terms of the numbers of households and/or persons falling within

particular income categories, household size categories, age categories, etc. Employment estimates are typically expressed in terms of equivalent, small-area projections of employment by place of work, broken down according to industry or land use category. Land use estimates are typically expressed in terms of the projected acres within each subregion falling within each of a number of specified use categories. The actual definition of the categories employed varies considerably from one model to the next, and in some instances within a given model depending on the level of sophistication employed.

All of the models incorporate some degree of "policy sensitivity"; that is, they are designed to reflect the impact which alternative policy decisions in one or more functional planning areas may have on the future distribution of urban growth. In each case, major emphasis is placed upon the treatment of transportation-related policies, particularly those which may be expressed conveniently in terms of conventional, network-oriented measures of transportation service. The actual treatment of policy variables within the models differs considerably from one formulation to the next. All of them utilize, however, to a greater or lesser extent, the outputs of conventional transportation network analysis as input to the calibration and forecasting process. Several of the models—perhaps the most notable ones in this respect are EMPIRIC and USM—have the capacity to deal also with other aspects of regional development policy, particularly those relating to future investments in public utilities, land use controls, development densities, and open-space and environmental planning.

The incorporation of policy sensitivity within the structure of the models allows them to perform an extremely important function within the overall transportation planning process. They provide the analyst with a mechanism, albeit in some cases a somewhat cumbersome one, to examine the feedback which exists between transportation development and the future pattern of urban growth. Early transportation planning studies were based essentially on the premise that a transportation system should be designed to service a particular configuration of land use and activity. That is, estimates were prepared of the future distribution of activity for each of a series of points in time, and these

were then used as a basis for developing future transportation plans. Experience has shown, however, that such a simple, uni-directional perspective provides only a very crude and inadequate base for effective planning. The implementation, and particularly the staging, of a transportation plan exerts considerable influence on the resultant growth of an urban area. It is, therefore, important that the analyst should have available a mechanism for assessing the probable impact of alternative transportation plans on the future distribution of growth and the consequent requirements for modification or expansion of the original transportation plan. The land use models outlined in this section provide the analyst with a capacity for such an evaluation.

The general role which any of the models discussed here may play within the work program of a typical regional transportation planning agency is illustrated in Figure 8. Three separate, but related, applications of the land use model, or activity allocation model as it is labeled in Figure 8, are depicted.

The narrow solid lines illustrate the use of the model as a simple, straightforward forecasting device, designed to break down regionwide forecasts of population, employment, and land use into equivalent, small-area estimates for use as input to subsequent transportation planning or related functions.

The dotted lines in the figure illustrate the use of the model in a simple feedback mode, in which it is used as a mechanism for assessing the impact of particular transportation or related planning policies on the future distribution of urban growth.

Finally, the heavy solid lines in the figure depict the use of the model in a more complex vein, as a vehicle for the analysis and coordination of planning programs or policies in two or more interrelated functional areas, including the assessment of the probable impacts of programs in one area on requirements in another.

An example of the first, simplest type of application might be employing a land use model to generate simple forecasts of small-area population, employment, and land use data

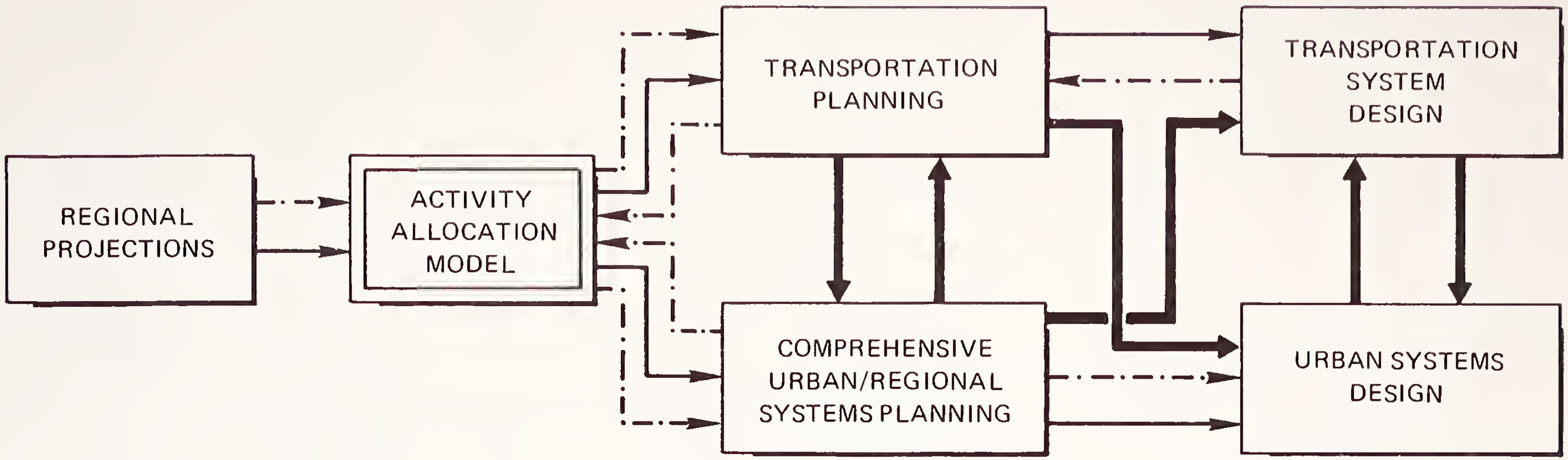

FIGURE 8: THE ROLE OF AN ACTIVITY ALLOCATION MODEL IN COMPREHENSIVE REGIONAL AND TRANSPORTATION PLANNING

as input into trip generation, trip distribution and modal split analyses supporting the development of a regional transportation plan. An example of the second type of application might be the use of the same model to assess the probable impact on future urban growth of two or more alternative transportation plans, including the probable geographic and social incidence of benefits and disbenefits stemming from each plan. An example of the third form of application might be the use of the model to coördinate regional transportation planning, regional open-space planning and regional utility system planning, by assessing the impact of specific programs in each of these areas in turn on requirements for the other two.

Land Use Modeling

Although the conceptual structures of the models discussed in this section differ widely, as do the techniques used in their calibration, all of them are applied in a similar, recursive format. That is, the models are applied repetitively, creating a set of successive forecasts for points 5, 10, 15, 20, etc., years into the future, with the outputs of one forecast being used as inputs to the next. The actual time interval employed varies considerably both from model to model and also between applications of the same formulation. The basic forecast principle, however, remains the same.

This recursive structure, though somewhat unwieldy, has two significant advantages. First, it permits the analyst to approximate a nonlinear pattern of growth over an extended time period, such as 20 to 30 years. Second, it provides the basis for performing the type of policy-oriented impact analysis outlined above, by permitting the analyst to assess the impact of policies implemented during one growth interval on the subsequent distribution of activity during the next interval.

The data requirements for the several models vary considerably in detail. All of them, however, require certain common pieces of information for their efficient application. These include:

- a detailed set of small-area (e.g., traffic zone or census tract level) data on population, employment and land use, most often broken down according to a number of preselected component characteristics, for the entire study region for a single, common point in time. Several of the models, notably EMPIRIC and to a lesser extent USM, require the assembly of compatible data for two separate points in time, usually between 5 and 10 years apart.

- selected information on the level of transportation service provided for the given "base year" or "base years," together with parallel information on trip length frequency distributions, travel impedance functions, etc. Depending on the precise formulation employed, this information on transportation service may be complemented by parallel data on public utilities investments, open-space and development controls, housing and employment location policies, etc.

- data on permissible future development densities, broken down by type of activity and potentially by individual small area or groups of small areas, together with parallel data on areas of land which are either to be withheld from any form of development or which are to be restricted to certain particular types of development.

- regionwide forecasts for each of the activities to be allocated by the model for the entire study region for each of the years for which small-area forecasts are to be prepared.

- data on the future planning policies to be pursued within the region, expressed in a format appropriate for input to the model. Such policy considerations are usually expressed in terms identical to those used to describe the levels of transportation and related services in the base year or years used for model calibration.

Each of the models has a number of specific data requirements in addition to those outlined above. They vary considerably, depending upon the formulation involved and the particular application for which the model is to be developed. In the case of USM, for example, data may be required on base-year pollution levels; in the case of PLUM, the categories of employment data are based upon a division of total regional employment into "basic" and "non-basic" categories; in the case of EMPIRIC, additional data is required for two points in time on the total population and total employment within each of a series of "external" districts outside the immediate periphery of the main study area. No attempt will be made here to develop these individual data requirements in detail. They are discussed at more length in Appendix D, which deals with each individual model.

The assembly of an adequate set of compatible data inputs for model calibration and application represents perhaps the single most arduous task in model calibration and application. It is essential that a solid, coherent foundation of base-year data be assembled if an effective model is to be calibrated. Experience has indicated that this may frequently take at least as long, and in some cases longer, than the time required for model calibration and application. Depending on the time period selected for calibration, much of the population and demographic data required may be derived from standard U.S. Census sources. Equivalent small-area employment and land use data is, however, considerably more difficult to obtain unless the local planning agency has either engaged in a recent transportation study or, more desirably, has instituted an effective process of data base development and updating. Policy inputs present a somewhat similar although usually less significant problem, particularly if the land use model is to be developed as part of an ongoing transportation or regional planning program.

The time frame and resource requirements for model development and application vary somewhat from one model to the next. As might be expected, they also vary depending on the scope of the application which is envisioned, the sophistication of the model, and the availability and quality of data. Past experience suggests, however, that it is extremely

difficult to undertake the effective development and application of any one of the operational models outlined in this discussion in less than 9 to 12 months, and for a total expenditure of resources of less than $75,000 to $100,000.

Alternative Approaches to Land Use Model Formulation - Some General Considerations

Before referring the reader to a discussion of the five individual models singled out for detailed review in Appendix D, it is appropriate to consider briefly some of the general points which underlie the development of models of this type. Six topics are of particular importance:

- conceptual structure;
- solution method;
- policy sensitivity;
- level of detail;
- transferability; and
- man-machine interface.

Each of these topics is discussed briefly in the following paragraphs.

Conceptual Structure

By far the most important considerations in model formulation relate to conceptual structure; that is, to the set of underlying hypotheses which serve as a foundation for model development, calibration, and application.

The conceptual structure of the five models discussed here varies considerably. Some of them—most notably PLUM and USM—build heavily upon a relatively rigid, deductive theoretical base, built around a prespecified theory or set of theories of the processes underlying urban development. Others—notably EMPIRIC and to a lesser extent, UPM—rely much more strongly upon efficient, inductive analysis of a comprehensive data set describing previous development trends

coupled with only a very broad theoretical underpinning. There are significant benefits and limitations associated with each approach. In abstract, a strong theoretical foundation for model development is perhaps the most appealing. In practice, however, such a structure must be considered only as a starting point for model development in a particular situation. If it is unduly rigid or unnecessarily complex, it may place excessive demands upon the ingenuity of the analyst to transform it into an operational tool in an environment different from that for which it was originally constructed and under conditions of stringent data limitations. The inductive approach, building around a broad, general conceptualization of the problem, though lacking in academic finesse, may well provide the analyst with considerably more flexibility to take full advantage of available data resources and to mold the model to the requirements of a particular application.

Two other general issues are also of importance here. The first of these concerns the treatment of time within the model. As noted earlier, all of the models discussed here employ a recursive forecasting format. Within this framework, however, they differ significantly one from the other in terms of their treatment of the time-related aspects of urban development. Several of the models, such as PLUM and the Opportunity-Accessibility Model, are explicitly cross-sectional in format. That is, they are based upon the calibration of relationships for a single point in time. By contrast, one of the models, EMPIRIC, is explicitly time-dependent in structure. It deals directly with changes in the distribution of activities over time, based upon calibration data assembled for two separate points in time. The other models, including PLUM and the Opportunity-Accessibility Model referred to above, address this issue only indirectly, through the incorporation of "lagged" variables reflecting the status of development at some point in time prior to the calibration base year.

In a related, but somewhat different vein, the models also differ significantly from one another in their treatment of the essential simultaneity of urban growth (that is, in their treatment of the interrelationships between activities and the change in distribution of these activities over time). Some of the models deal with this only at a relatively

superficial level. Others, such as PLUM and USM, treat the issue in terms of explicit transportation-oriented relationships between residence location and work place location. Two of the models, EMPIRIC and UPM, incorporate a more complex structure of interrelationships based in one case (UPM) on measures of the relative desirability of individual districts for different types of development and in the other (EMPIRIC) on the description of changing patterns of development as a set of explicit, simultaneous equations.

Again, there are significant arguments which may be made for and against each type of structure: Desirably, one would prefer in abstract a model which dealt explicitly with the change over time rather than with relationships calibrated for a single point in time, and which also dealt explicitly with the simultaneity of development. In practice, however, this requires either a more complex, *a priori* theoretical structure on the part of a "deductively" oriented model, or else reliance upon relatively extensive "inductive" analysis to serve as a foundation for model development in a given situation. Equally important, effective treatment of change over time in the distribution of activities requires the development of data for at least two points in time, rather than just a single point.

Solution Method

Each of the models discussed here employs a somewhat different set of solution procedures. In some cases—for example USM—the calibration process is founded upon a relatively complex, *a priori* theoretical structure and is relatively simple. In others, notably EMPIRIC and UPM, the solution process is considerably more complex. In one case it requires the calibration of a set of simultaneous regression equations, in the other it requires the estimation of a series of nested utility functions. Both of these approaches imply a significant level of expertise on the part of the analyst.

Similarly, some of the models employ direct estimating procedures within the forecasting process while others rely upon iteration to achieve a single, balanced solution for each point in time. Such iterative solutions, provided that they are based upon efficient, convergent algorithms,

present no really serious problem. If such an algorithm does not exist, however, they may represent significant handicaps, particularly if the model is to be applied repetitively to test a variety of different policy scenarios.

Each of the models is subjected, within the solution process, to a variety of different constraints. In some instances (e.g., PLUM), such constraints are treated explicitly within the formulation of the model. In others, such as EMPIRIC, they are implicit in the procedures used for forecasting. In either case, it is essential that the analyst have a clear understanding of the implications of such constraints and the procedures to be invoked in imposing them before attempting to apply the model. This point is of particular significance in terms of the conversion of "head-count" estimates (e.g., estimates of population and employment) into equivalent land areas.

Policy Sensitivity

As noted above, all of the models discussed here incorporate explicit attempts to reflect the impact of one or more types of planning policy on the pattern of urban development. They do so in different ways and with varying degrees of success. In evaluating their relative policy sensitivity, three important points should be borne in mind.

First, experience has shown that there is a considerable degree of inertia associated with urban development. That is, future patterns of development tend to be heavily contingent upon the established distribution of activity in a given base year. This means that within the models the impact of specific "policy variables" is in most instances dominated by other measures, reflecting the established pattern of development at the start of the forecasting interval.

Second, it is only too easy to exaggerate the impact which one particular policy, such as transportation investment, may have on the pattern of urban growth simply by ignoring other, parallel policies. Experience and common sense indicate strongly that a multitude of factors influence the evolving pattern of growth in a metropolitan area. It is infeasible to incorporate more than a limited number of these considerations within an operational land use model.

Considerable caution, therefore, must be exercised in interpreting the sensitivity of a particular model to those limited policy variables which are incorporated within its structure. Caution must also be exercised to avoid unduly enthusiastic extrapolation of what may be potentially spurious, or at best only associative correlations.

Finally, it should be noted that, whether the model incorporates explicit time dependence or whether it is based upon a simple set of cross-sectional relationships, major problems are posed when it is used to evaluate the potential impact on future urban growth of policies totally different from those which have been invoked in the past. A simple example of this is the use of a land use model to evaluate the probable impact on future urban growth of the construction of a rapid-transit system in an area which previously was provided with only meager and relatively unchanging transit service. In such a case the analyst must resort necessarily to carefully controlled extrapolation of previous development trends either within the area under analysis or in other areas.[1]

Level of Detail

Considerable caution must be exercised to avoid the temptation to try to develop a model at a level of detail which is conceptually appealing but which is operationally totally intractable. Several of the earliest attempts at land use model development fell into this trap with a resounding splash. They attempted to deal comprehensively with the entire urban system, incorporating a complex net of interrelationships built around a theoretical structure whose solution was not wholly defined and whose data requirements were massive. The attempt to deal "holistically" with the entire urban system rather than with selected portions of that system was, perhaps, the most significant reason underlying their operational failure.

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[1] This point will not be pursued in more detail here. It is discussed at some length in a number of references contained in the bibliography, especially in PMM&Co., (1972[a]) and PMM&Co., (1973).

More recent models, particularly the five selected for detailed review, have attempted a more realistic approach. They focus on a relatively crude abstraction of the development process, and make little or no pretense to deal effectively with more than two or three of its more important dimensions. Even so, considerable caution must be exercised in their application to avoid attempts to make these models unrealistically specific in either geographical or functional terms.

Geographically, they represent devices to break down regionwide forecasts of future activity into a lesser number of geographical subregions. There are both practical and conceptual limitations on the number of subregions which may be employed in each of the models. In practical terms, an increase in the number of subregions (e.g., traffic zones) for which forecasts are to be attempted beyond the level of 200 to 300 separate units may significantly increase the costs both for data assembly and model application. More importantly, it is questionable whether any of these models have a realistic capacity to project the future distribution of activity, particularly for points 20 or 30 years into the future, at a level significantly below that of the conventional census tract. Attempts to create too fine-grained a system of subregions are likely to be expensive and also unsatisfactory in terms of the quality of the results produced.

In functional terms, all of the models discussed have the ability to produce basic estimates of population and employment counts, together with equivalent land use estimates, for input to the travel forecasting and related processes. These basic forecasts may be disaggregated by means of a series of submodels operating on the outputs of the main model. Again, however, considerable caution should be exercised with respect to the number of such submodels which are employed and, particularly, with respect to the interpretation of the resulting outputs. Just as the models are constrained geographically in terms of the number of small-area units with which they may effectively be concerned, so also are they constrained in terms of the totality of functional outputs which they may generate. Attempts to generate too broad a collection of outputs may again result only in a collection of spurious numbers.

Transferability

Transferability—the capacity to transfer and successfully operate the model under a variety of different conditions—is perhaps the single, most critical facet of an operational computer model. All of the models discussed here are transferable to a greater or lesser extent. Some, particularly PLUM, USM, and EMPIRIC, have been applied successfully under a number of different operational environments, and have associated software, documentation, and staff-support characteristics which make their transfer from one environment to another relatively easy to achieve. The other two models are somewhat less transferable, primarily because of a lack of readily available staff support for the transfer activity or because the model has not been fully proven in an operational sense.

At least three major factors should be taken into account when considering transferability of an individual model:

- Operational Software: The set of computer programs making up the model should form a single, integrated package which is operational on as wide a range of computer hardware as possible. Ideally, the programs should be maintained on a continuing basis and should, if at all possible, have been in continuous application over the recent past.

- Staff Support: A full degree of transferability can only be attained if a model is provided with adequate staff support of persons experienced in its previous application to assist in the transfer process.

- Supporting Software: All five models discussed in this section require a significant investment by the user in data assembly. To be fully transferable, the models should, therefore, be accompanied by a comprehensive set of data assembly and analysis routines to support the construction of the input data files.

Man-Machine Interface

Effective application of an urban growth model requires that provision be made for a significant degree of interaction between the analyst and the computerized operation of the model. Ideally, the analyst should be able both to mold the model to his particular requirements and also to inject a series of discrete constraints or limitations upon the forecasting process. This in turn requires that explicit provision be made for such activities within the design of the computer software. This feature is incorporated to varying degrees in all of the models discussed here. It is probably treated most extensively as an explicit consideration in the case of the EMPIRIC model. This treatment, however, stems in part from the basic structure of that model and its intended method of application. All of the other models, and most particularly PLUM and USM, provide for a meaningful degree of man-machine interaction at appropriate points within the model calibration and forecasting process.

Comparison of Land Use Models

Land use models have been under development in the United States and elsewhere for the past 20 years. No attempt will be made here to review this development in detail. Reference is simply made to a number of excellent review articles available in the published literature. Most notable of these are the articles due to Lowry (1968), Hemmens (1970), Goldner (1971b), Boyce and Day (1969), Kilbridge *et al*. (1969), and H. J. Brown *et al*. (1972).

Lowry's paper provides a review and analysis of seven prominent land use models developed in terms of a paradigm of the urban land market which forms the basis for classifying models according to whether they focus on land use patterns, location patterns, or other strategies of model design. His review, though prepared in 1967, includes a number of the models discussed in this section. Hemmen's paper is more recent in vintage, and discusses very effectively the role which land use models may play within the overall transportation planning process. Again, he makes reference to several of the specific formulations discussed here. Goldner's paper reviews the development of a sequence of models based upon an initial formulation developed by

Lowry in 1962-1963. Goldner traces the several developments and amplification of Lowry's original work, including significant work performed both in the United States and overseas. Two of the five models discussed here (PLUM and USM) are derivatives of Lowry's original work. Boyce and Day include a discussion of four land use models as one chapter within a broader report on comprehensive plan making. Their discussion includes Lowry's original formulation together with the EMPIRIC and Opportunity-Accessibility Model discussed in this section. Kilbridge et al. present a generalized, conceptual framework for urban planning models incorporating an extensive review of previous work up to 1968 and a commentary on their relative strengths and weaknesses. Finally, Brown et al., in a 1972 monograph published by the National Bureau of Economic Research, present an elegant discussion of the recent history of land use model development in the United States. Their discussion includes one of the models (PLUM) selected for detailed treatment in this report. The monograph is notable primarily for an excellent though somewhat brief commentary in the final chapter on problems and future directions for research.

Two additional references should also be cited here. Both are methodological in orientation, and provide a useful supplement to the materials discussed in the preceding section. The first is a paper by Lowry (1965), in which he provides the reader with a simple set of guidelines for model development. The second, by Seidman (1968), presents a pragmatic view of some of the operational difficulties associated with model development. It is notable particularly for the honesty with which it addresses a number of crucial problems of an operational rather than a conceptual nature.

Table 7 summarizes the comparison of the land use models reviewed.

Model	ts	Limitations
PLUM	Acti ure; Allo onal with Land viability; Mode ortation	Limited outputs; cross-sectional calibration; data requirements high; exogenous projection of "basic" employment.
USM	Acti ure and Allo ibration; Land perational; Mode d to rtation rams.	Some limitations on outputs; exogenous projection of "primary" employment; basic cross-sectional calibration; data requirements high; proprietary package.
EMPIRIC	Acti -dependent Allo lly opera- Land emonstrated Mode licy orienta- ve outputs ed to other ing programs.	No <u>unique</u> structural base; data requirements high (two points in time); efficient calibration dependent on skill of analyst.
Opportunity-Accessibility Model	Acti structure; Allo ents rela- Land ransporta- Mode ion.	Very limited outputs; no continuing staff support; lack of non-transportation policy sensitivity; cross-sectional calibration.
UPM	Acti nceptual Allo me- Land ibration; Mode n orien- e output ic model	Very complex structure; conventional forecast outputs limited; residential orientation; confusing calibration process; data requirements high; cross-sectional calibration.

TABLE 7

COMPARISON OF LAND USE MODELS REVIEWED

Model	Type	Methodology	Resource Requirements	Availability	Merits	Limitations
PLUM	Activity-Allocation/ Land-Use Model	Cross-sectional; structural (Lowry-type); fully computerized.	CDC 6400 or IBM 360/40 with 256K bytes for 300-zone study area; approx. 10-15 hrs. machine time required in total; 1 to 1-1/2 man-years professional time plus technical support.	Public domain (FHWA). Staff and program maintenance support available from University of California.	Simple structure; fully operational with demonstrated viability; strong transportation orientation.	Limited outputs; cross-sectional calibration; data requirements high; exogenous projection of "basic" employment.
USM	Activity-Allocation/ Land-Use Model	Structural; lagged, cross-sectional (Lowry-type); fully computerized.	IBM 360 with 250K bytes. Machine time and manpower needs uncertain but probably similar to PLUM.	Proprietary to Alan M. Voorhees & Assoc. Staff and program maintenance support available.	Simple structure and efficient calibration; basic model operational; outputs linked to other transportation planning programs.	Some limitations on outputs; exogenous projection of "primary" employment; basic cross-sectional calibration; data requirements high; proprietary package.
EMPIRIC	Activity-Allocation/ Land-Use Model	Time-dependent; econometric/ structural; fully computerized.	IBM OS 360/40 with 100K bytes or equivalent for 200-zone study area. Approx. 15-25 hrs. machine time required in total; 1 to 1-1/2 man-years professional time plus technical support.	Public domain (FHWA). Staff and program maintenance support available from PMM&Co.	Flexible time-dependent structure; fully operational with demonstrated viability; policy orientation; extensive outputs directly linked to other transp. planning programs.	No unique structural base; data requirements high (two points in time); efficient calibration dependent on skill of analyst.
Opportunity-Accessibility Model	Activity-Allocation/ Land-Use Model	Cross-sectional; statistical ("opportunity" model); fully computerized.	IBM 7094 and Burroughs B-5500; machine time and manpower requirements uncertain, but certainly less than the other models on this list.	Public domain (N.Y. State DOT); no direct program maintenance or staff support available.	Very simple structure; data requirements relatively low; transportation orientation.	Very limited outputs; no continuing staff support; lack of non-transportation policy sensitivity; cross-sectional calibration.
UPM	Activity-Allocation/ Land-Use Model	Time-dependent; statistical/ utility theory; fully computerized.	IBM 360 computer storage; machine time and manpower requirements not specified but probably in excess of others on this list.	Initial version public (DOT/OST); final version proprietary to RSA, Limited; staff and program maintenance support available.	Attractive conceptual structure; time-dependent calibration; transportation orientation; unique output measures; basic model operational.	Very complex structure; conventional forecast outputs limited; residential orientation; confusing calibration process; data requirements high; cross-sectional calibration.

5. CONCLUSIONS AND RECOMMENDATIONS

SUMMARY OF ACCOMPLISHMENTS

PMM&Co. has conducted an extensive bibliography search and detailed review of urban transportation planning models. The model review reports summarized in Section 4 and presented in detail in Appendixes A through D comprise an up-to-date and fully integrated documentation on urban transportation planning models of operational or near operational status. This report will be extremely useful to the Transportation Systems Center and other U.S. Department of Transportation agencies having systems analysis and transportation planning responsibilities. By reference to this report, a rapid assessment can be made of the applicability, resource requirement, and theoretical soundness of each model. The utility of specific urban models for urban planning problems and transportation systems analysis can be investigated, with minimal cross-reference to other sources.

Many of the models referenced and reviewed should be useful to TSC in undertaking its own urban transportation planning studies and other national needs studies. PMM&Co. believes that the UMTA Transportation Planning System (especially the interactive sketch planning versions) and the TRANS-Urban Model (with appropriate modifications as an urban aggregate planning model) offer considerable utility, and that specific applications should be further investigated.

FUTURE EXTENSIONS

Current urban transportation planning techniques require the development of a substantial data base, the coding of detailed transportation networks, and the application of a complex and costly set of computer planning tools. Approximately 70 percent of urban planning funds is devoted to the "front end" data and model preparation, less than 20 percent is available for plan evaluation and testing, and the remaining 10 percent is devoted to miscellaneous fixed expenses. An analysis of urban transportation problems requires from 12 to 24 calendar months. Consequently, there is an urgent requirement to improve the planning process by developing a

system that requires less data, little or no new network coding, and quick, inexpensive computer runs. This will permit the planner to rapidly evaluate several alternative transportation system proposals in a few days' time.

There is a need to reduce data costs through network and data abstraction approaches, applying national data files from the Bureau of the Census and precoded urban street network systems developed in the typical urban comprehensive, cooperative and continuing planning programs. Geocoded data files, computerized mapping, and computer graphic display techniques need to be extensively used. In addition, there is a need to develop improved models for land use, traffic forecasting, assignment, and evaluation that are fast and efficient, requiring minimal computer resources. The reduced data requirements, coupled with new transportation planning algorithms, will enable the urban transportation planning process to be implemented interactively with advanced graphics and cathode ray tube (CRT) computer terminals and analyses performed in a few hours or days, thereby minimizing manpower and computer resources.

Greatly improved data management file systems must be developed to enable the rapid and economical processing of extensive urban data bases. All urban data should be converted to a geocoded basis, now possible using CRT terminals with graphics tablets for automatic digitizing of map referenced data. A completely geocoded data file will enable computer mapping and automated graphic display of planning information.

Major areas of required transportation modeling research include the development and implementation of time dependent, structural land use models; behavioral, stochastic and disaggregate direct demand modal formulations; automated network aggregation techniques to simplify network analysis; multimodal, multipath traffic assignment algorithms; and improved cost-benefit/impact models for evaluation of transportation systems. A sustained annual budget in the hundreds of thousands of dollars over the next five years is required to successfully complete this research program. PMM&Co. recommends that a detailed research program be prepared.

APPENDIXES

INDIVIDUAL MODEL REVIEW REPORTS

Individual review reports on each model are appended here under the following categories:

Appendix A: Demand Models

Appendix B: Network Models

Appendix C: Cost-Benefit/Impact Models

Appendix D: Land Use Models

The classification is made merely as a convenient reference scheme; the individual review reports are self-contained documents. Each can be extracted for use as an independent summary of a model. The following pages list the 19 review reports alphabetically.

APPENDIX A

DEMAND MODELS

APPENDIX A

DEMAND MODELS

APPENDIX A-1

TRIP GENERATION MODEL

INTRODUCTION

Trip generation refers to one of the initial phases in Urban Transportation Planning (UTP) in which trip volumes at origins and destinations are estimated, usually for future years, from a number of socio-economic variables. Multiple regression is the most commonly used technique to relate trip generation to its explanatory variables. Standard computer programs are available within the FHWA Urban Transportation Planning Battery to perform this type of analysis.

THEORY AND CALIBRATION

The usual regression format is used, where the trip productions or attractions at Zone i, T_i, is expressed as a linear equation of a number of explanatory variables, F_k,:

$$T_i = a_1F_1 + a_2F_2 + \ldots + a_nF_n$$

where we have shown n explanatory variables in the equation.

The trip productions and attractions (collectively called trip ends) are generally stratified by the following categories:

. Zonal vs. Household Trips

. Person vs. Vehicle trips

. Trip Purpose: Work
Shop and Personal Business
Social and Recreational
School

. Home-based vs. non-home-based

For each type of these trips, a different subset of explanatory variables may have to be selected from the following master list (excerpted from [DOT/FHWA-1972]):

1. Variables found significant in zonal trip generation analysis

a. Demographic Data

(1)	Total population	1*
(2)	Age, sex, race, etc.	3
(3)	No. of household units	1
(4)	School enrollment	2
(5)	Family life cycle	3

b. Economic Data

(1)	Total employment	1
(2)	Selected employment	1
(3)	Employment by industry	3
(4)	Employees by residence	1
(5)	Labor force	3
(6)	Labor force by occupation and industry	3
(7)	Median income	1
(8)	Income stratified	3
(9)	Automobile ownership	1
(10)	Dwellings without autos	2
(11)	Retail sales	2
(12)	Average home value	3

c. Land Use Data

(1)	Specific activities	3
(2)	Selected categories	1

2. Variables found significant in dwelling unit trip generation analysis

(1)	Car ownership	1
(2)	Family size	1
(3)	No. of persons 5 years old, and over in household	1
(4)	Length of residence	3
(5)	Family income	2
(6)	No. of persons 16 years old and over	2
(7)	No. of persons 16 years old and over who drive	1

*Key to weights: 1 = Essential data; 2 = Desirable data; 3 = Useful data.

(8)	Age of head of household	2
(9)	Distance from CBD	3
(10)	Stage in the family life cycle	1
(11)	Occupation of head of household	1
(12)	Structure type	1

*Key to weights: 1 = Essential data; 2 = Desirable data; 3 = Useful data.

Not all of these variables are independent of each other. For example, vehicle ownership is correlated with family income -- that vehicle ownership tends to be high when family income is high. When both variables are included in the regression equation, the problem of "collinearity" arises in the statistical analysis.

As with standard regression, the "goodness of fit" of the equation to data is typically measured by multiple correlation coeff, R^2, standard error of estimate, and t tests. To select the most relevant explanatory variables to be included in the equation, a simple correlation matrix can be used to check the association between all the variables -- both the explanatory ones and the variable to be estimated.

The production and attraction equations are independent of each other; when all zonal production or attraction values are summed, the results are two independently calculated regional totals for each trip purpose. A common practice is to equal, or set equal, the regional total production and attraction values for each trip purpose.

APPLICATION

Trip Generation is an essential task to be performed in every transportation study. To compile a complete list of the urban/regional areas where trip generation analysis is performed would be a formidable task. The following examples of the trip generations are quoted for illustration purposes only.

In the Penn-Jersey Study around 1960, trip generation was performed under the following stratifications:

Land Use Category	Trip Type	Mode
Residential	Home to work Home to non-work	Auto Mass Transit Truck Taxi
Non-Residential: Office, Retail, Manufacturing, Public Utility, Recreation	Work to Home Non-work to Home Non-home-based	

PMM&Co. performed a "Model Validation" Study in Eastern Massachusetts. An objective of the study was to validate the trip generation technique used in the Eastern Massachusetts Traffic Forecasting Model against sampled data. The findings reflect two places where users of the technique should be cautious about: the first arises from the intrinsic structure of the trip generation model, while the second is perhaps inherent with most statistical analysis.

Weaknesses intrinsic to the model:

- Trip productions are usually more accurate than attractions due to the fact that surveys are usually conducted at the trip production end -- in the form of home interviews.

- The process of balancing trip productions and attractions in a study area introduces inaccuracies.

General Statistical fallacies:

- Most of the systematic "errors" in the study can be traced to errors that occurred in the reallocation of socio-economic and trip end data among zones -- a data grouping problem.

- The model does better at predicting traffic zones with large volumes of trip ends than for zones with small volumes of trip ends -- a sample size problem.

Average computer run times are quoted here from a sample of regional users of the FHWA trip generation programs. For a medium size city (probably with traffic zones ranging from 600 to 900), it took 24 minutes clock time for input data pre-processing, 10 minutes for the actual regressing coefficient computation, and another 9 minutes for "plugging" the explanatory variables in the equation to arrive at the estimated trip ends. All computations were carried out on a 370/155 machine.

CONCLUSION

Trip generation analysis is mainly an effort in performing linear regression. Although alternative "state-of-the-art" techniques such as "cross-classification" and "econometrics" type model exists, practicality considerations (such as the availability of packaged programs) still strongly favor regression. The success of applying the technique hinges on (i) the completeness of the data base, (ii) the user's familiarity with statistical analysis, and (iii) his transportation planning experience (e.g., in manipulating survey data and balancing productions and attractions).

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APPENDIX A-2

THE GRAVITY MODEL

INTRODUCTION

The gravity model is a well-known and commonly used technique for estimating zonal trip interchanges. It is a part of two widely used urban transportation planning systems: the Federal Highway Administration's (FHWA) Urban Transportation Planning System 360 and the DCO/TRANPLAN battery developed by DeLeuw, Cather, and Company and Control Data Corporation. The large majority of urban area comprehensive transportation planning studies done in this country have utilized the gravity model.

THEORY

The gravity model, derived from Newton's law of gravity, says that the trip interchange between zones is directly proportional to the relative attraction of each of the zones and inversely proportional to some function of the spatial separation between zones. This relationship can be expressed as follows:

$$T_{ij} = P_i \frac{A_j \, F_{ij} \, K_{ij}}{\sum_j A_j \, F_{ij} \, K_{ij}}$$

where:

T_{ij} = trips produced in zone i and attracted to zone j

P_i = trips produced by zone i

A_j = trips attracted by zone j

F_{ij} = empirically derived traveltime factor

K_{ij} = zone-to-zone adjustment factor

Trip productions and attractions, input from trip generation procedures, are defined in accordance with the classification of all trips as either home-based or non-home-based. Home-based trips, which have one end at the residence of the tripmaker, are always produced by the zone of residence whether the trip begins or ends in that zone. Home-based trips are always attracted at the nonresidential end of the trip. Non-home-based trips are always produced by the zone of origin and attracted by the zone of destination.

Traveltime factors, also known as friction factors or propensity factors, express the effect that spatial separation exerts on trip interchange. This separation is most often measured by total traveltime between zones. The factors are roughly an inverse exponential function of the travel times. Several sets of factors are normally used depending on the number of trip purposes.

The zone-to-zone adjustment factors, familiarly known as K-factors, are used to allow for effects on travel patterns by social and economic influences not accounted for in the gravity formulation.

Several assumptions, in which lie the main weaknesses of the gravity model, are implied in the use of the gravity theory:

- An average travel pattern can be applied to all zones within the urban area regardless of zonal social and economic characteristics.

- The travel pattern is independent of relative zonal locations.

- Trip length distributions (by purpose) remain constant through the urban area.

- Inter-zonal travel times remain constant and inaccurately reflect the time period chosen.

CALIBRATION

Data required for gravity model calibration include zone-to-zone trip tables (whose source is usually a travel survey) and zone-to-zone travel times (developed through network coding procedures). The trip tables are often stratified by up to eight or more trip purposes. They may be comprised of vehicle trips or person trips, usually depending on the type of modal split analysis to be done. Person trip tables are needed for detailed transit analyses.

An initial set of traveltime factors is required. Considerable effort can be saved if a set of factors already determined for an area of similar size is used as a starting point. Otherwise, factors all equal to one are often used.

The gravity model calibration operates by computing a set of trip interchanges using the initial input data. Trips attracted to each zone are then compared with surveyed attractions. The program will then adjust each zonal trip attraction factor

by the ratio of the origin-destination attraction factor to the gravity model calculation. Finally, an entirely new set of trip interchanges is calculated using the adjusted attractions and, if necessary, the process automatically repeated.

A trip length frequency distribution is usually used as a basis for comparison of trip interchanges computed from the gravity equation with surveyed trip interchanges. If the trip length frequency distribution produced from the gravity output is not reasonably close to the survey distribution, then adjustments are made to the traveltime factors by a manual iterative procedure. Normally, about three calibration runs are required to produce an acceptable trip length distribution.

Several zone-to-zone adjustment factors are usually required to bring certain estimated volumes in line with surveyed volumes. The reasons for these adjustment factors include the following.

- The trip purpose stratifications used may not be precise enough.

- The average traveltime factor may not reflect behavior accurately.

- Income, residential density, and other socioeconomic factors affect trip interchanges.

Various utility programs are available in the urban transportation packages which perform statistical tests in comparing the gravity model "synthetic" data with actual. Considerable manipulation of traveltime and adjustment factors may be required to produce results comparable to observed traffic patterns.

Machine running time for the FHWA's gravity model program was about one-half hour per run on the IBM 370/155 for the Boston area's 894 zones and 5 trip purposes. The cost was approximately $300 per run. For the Detroit region's 1,496 zones, a TRANPLAN gravity model run required 50 minutes on the Control Data 6600 at an approximate cost of $900 for 7 trip purposes. Calibration of the gravity model, exclusive of initial data preparation, normally requires one to three man-weeks.

APPLICATION

The forecasting application of the gravity model is similar to the calibration process except that the calibrated friction factors and K factors are used along with future trip productions and attractions. Several trip summary tables and statistical measures are available as output options.

CONCLUSION

The gravity model has become the standard technique for distributing trips in urban areas. Although many factors affecting travel behavior are neglected or, at best, covered by adjustment factors, its ease of understanding and application make it appealing. Model accuracy is normally high enough to make the model useful for most applications.

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APPENDIX A-3

THE INTERVENING OPPORTUNITY MODEL

INTRODUCTION

The Intervening Opportunity Model (IOM) originated in the Chicago Area Transportation Study (CATS) around 1960. Second to the Gravity Model, it is one of the widely known trip distribution models. The IOM is packaged within the FHWA battery of programs and is readily available for public use.

THEORY

The IOM is one of the few distribution models which is based on a probabilistic formulation, which states that the probability, dP, that a trip will terminate in a zone is the "joint probability" that no termination point has been found in the volume of destinations, D, in zones closer to the origin, and that the additonal volume of destinations, dD, subtends an acceptable termination point:

$$dP = [1-P(D)]LdD$$

where $P(D)$ = the probability that an termination point is found in the volume of destinations D

L = a constant probability that a destination point is indeed the termination point

Solving this differential equation for P(D), the probability of finding a termination point in D destinations, we have,

$$P(D) = 1-\exp(-LD)$$

The expected number of trips from i that will terminate in j, T_{ij}, is obtained by multiplying the total number of trips originating at i, T_i, times the probability that the trip will terminate in the D_j volume of destinations:

$$\begin{aligned} T_{ij} &= T_i[P(D+D_j)-P(D)] \\ &= T_i\{\exp(-LD)-\exp[-L(D+D_j)]\} \end{aligned}$$

Similar to other distribution models, an iterative procedure has to be employed to ensure that all (or most of) the generated trips are distributed, and that the destinations summed up to the desired figures.

CALIBRATION

Basically, IOM is calibrated by varying the L values until a satisfactory simulation (by traffic assignment) of existing (or projected) travel patterns is obtained. For example, an L is found so that the observed average trip length is duplicated within 10%, that link volumes checked out, cordon counts match, or total veh-miles of travel conserved. Both manual and iterative numerical calibration procedures have been reported.

Either a single L value is to be calibrated for the study area, or that multiple L's would be used for residential vs. non-residential areas, long vs. short trips, etc. Different L's are usually obtained for different trip purposes.

The calibration of IOM is by no means trivial to inexperienced personnel. There have been various reports on the amount of efforts involved in computing L. A large amount of the discussion hinges on whether L, the probability that a zone is accepted as a termination point, should be a constant for all study areas, trip purposes, origins, and different time periods of the study.

APPLICATION

IOM has been used in a number of transportation studies. The Chicago Area Transportation Study (CATS) probably used the model most extensively. Later studies in Pittsburgh and Upstate New York also employed IOM extensively.

A series of calibration studies using the 1948 and 1955 Washington, D.C. survey data and the 1960 Honolulu Metropolitan Area Traffic Survey data were carried out by the U.S. Bureau of Public Roads around 1966, which culminated in the inclusion of the IOM in the FHWA battery of programs.

Machine run-time for the IOM is around half an hour on the IBM 370/155 for about 900 zones and 5 trip purposes. Calibration, exclusive of initial data preparation, requires one to three man-weeks.

CONCLUSION

The IOM, with its probabilistic description of trip interchange, has a behaviorally attractive formulation for

similating travel pattern. However, it is not as widely used as the other distribution models (e.g., the Gravity Model), mainly for two reasons. First, the formulation is not as easy to understand. Second, the accurate calibration of L factors represent a fair amount of effort and experience.

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APPENDIX A-4

TRC MODAL SPLIT MODEL

INTRODUCTION

The Traffic Research Corporation (TRC) modal split model is one of the earliest and (relatively) most successful trip interchange models. It opened the road to many similar models. The model originally developed for Toronto in the late 1950's has been applied in several North American cities such as Washington, Boston, Philadelphia, Baltimore, Detroit, San Francisco, and Las Vegas. In the late 1960's, it underwent considerable refinements and "automatization" in Boston by Peat, Marwick, Mitchell & Co.(which merged TRC) where it has been used for the planning of several rapid transit corridors.

THEORY

The model, set in a very flexible format, treats binary choices between automobile and transit. The binary choice is imposed by the graphical approach to calibration. Essentially, it was postulated that (transit) modal split is a function of the purpose of the trip, the economic status of the tripmaker, the systems attributes, and the time of the day. The following basic factors are considered:

- trip purpose - work, non-work;
- economic status of the tripmaker - average or median yearly income;
- ratio of total travel time by transit to total travel time by automobile;
- ratio of total out-of-pocket cost by transit to the total out-of-pocket cost by automobile;
- level of service defined as the ratio of out-of-vehicle (excess) time by transit to out-of-vehicle time by automobile.

Also considered but not retained were trip length, population density, employment dnesity, transit seat capacity,and directionality of the trip with respect to the central business district.

The modal split curves, which were hand-fitted, relate transit modal split to the travel time ratio variable. The remaining variables were used as stratification variables.

Thus, for a given trip purpose, five income classes, four cost ratios, and four service ratios were defined, producing a total of 80 curves. The final shape of the curves was obtained by search so as to minimize discrepancies between observed and estimated modal splits, and to obtain a general consistency within and between each stratum.

The advantages of the methodology include the following:

- It recognizes explicitly the importance of excess time as the variable to which transit modal split is the most sensitive.

- It allows the use of non-linear relationships.

- It allows the analyst to maintain modal split between 0 and 1 and to control certain "discrepancies" in the calibration sample.

- Certain similar "trends" appear in the comparison of the sets of curves derived for different cities.

The model, however, presents several shortcomings. Being a binary choice model, it forces the analyst to lump together all transit modes. It considers a limited set of modal attributes, some of which are difficult to define, such as out-of-pocket auto cost. As in all aggregate models, the representativity of average or median measures is doubtful; the estimation of observed modal splits is highly sensitive to sample size, thus forcing the analyst to reject observations below a certain threshold. Finally, the use of ratios as variables causes many problems in degree of sensitivity where extreme values of the impedances occur.

CALIBRATION AND APPLICATION

The model was originally calibrated using Washington, Philadelphia, and Toronto data. Although the calibration program, which is proprietary to Peat, Marwick, Mitchell & Co. (PMM&Co.), is operable, the calibration is a tedious process which requires considerable data combined with subjective analysis. Subsequent studies, therefore, have used the modal split curves with their original values, in a few cases utilizing city-specific adjustments which increase or reduce the modal splits according to available historical data. It is believed that the curves provide logical relationships sufficiently accurate for most planning sutdies and, in particular, for a basis of comparison between several transit alternatives.

PMM&Co. has developed a computer routine to perform the modal split computations. This routine is available as a stand-

alone program useful for small studies and sensitiviity analyses, and as part of an overall transit package (Automated Corridor Model) used in conjunction with the FHWA Urban Transportation Planning System 360. In both formats the input data consists of zonal incomes, highway and transit travel times, excess times, and costs. The program computes the ratio variables, calculates the modal splits, and adds the adjustments, if any. Machine running for a Boston study was on the order of three IBM 370/155 minutes for 60,000 interchanges, or about $30.

EXPERIENCE

Two large applications of the TRC model have been carried out in Boston: rapid transit planning studies for the Massachusetts Bay Transportation Authority and 1990 urban area studies for the Massachusetts Department of Public Works. The model has also been used for forecasting in a study done for the San Francisco Golden Bridge Authority and in a study done for the Bendix Corporation of a monocab system in Las Vegas. Most recently, the curves were incorporated into the Control Data Corporation's TRANPLAN System for use in the Detroit area's comprehensive planning program by the Southeast Michigan Council of Governments.

CONCLUSION

The TRC modal split model will produce reasonable results in analyses where transit service can be represented by a single mode. Operation of the model is simple and inexpensive. However, its usefulness is limited where there are several modes or where more transportation variables are desired.

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APPENDIX A-5

THE PRATT MARGINAL UTILITY MODEL AND THE LISCO PROBIT MODEL

INTRODUCTION

The Marginal Utility Model, developed by R. H. Pratt in the late 1960's, is a binary choice trip interchange modal split model. It has been used in at least three recent metropolitan area transportation studies: Los Angeles, Chicago, and the Twin Cities. The Lisco Probit Model, which bears close similarities to the Utility Model, was used in a study of the value of commuters' time in Chicago.

THEORY

The Marginal Utility Model is a binary choice model whose basic premise is that the characteristics of the transportation system can be transferred into a disutility measure, which, in turn determines modal split. It is theorized that, given a variable defined to explicitly or implicitly represent the datum on which people base decisions, the distribut n of the results plotted against values of the variable will approach normality. If a decision variable can be found to represent all perceived travel disutility, and if the results of dependent variable observations show a normal distribution, then it may be assumed that the decision variable is adequate.

The same basic assumptions are made in the Probit Model formulation. However, certain variables, such as age and sex, which do not act in accordance with the cumulative normal function, are included by appropriate transformation to conform to the normal S-shaped curves.

In both theories an equation--termed the marginal disutility equation and the linear probit equation, respectively, forms the basis of the models. The marginal disutility equation is comprised of the differences between auto and transit impedance variables.

$$U = a_o + a_1 (T_1-V_1) + a_2 (T_2-V_2) \ldots\ldots a_n (T_n-V_n)$$

where:

U = marginal disutility

a_n = variable coefficient

T_n = transit impedance variable

V_n = auto impedance variable

In two of the studies using the Marginal Utility Models, manual curve-fitting techniques were used to relate transit modal split to the U function. The other study utilized multiple regression to determine the weighting factors after converting the dependent variable values to a cumulative normal scale.

The probit equation took the following form:

$$Y = a_o + a_1 \Delta T + a_2 \Delta C + b_1 X_1 + b_2 X_2 \ldots . b_n X_n$$

where:

a_n, b_n = coefficients of the variables

ΔT = transit travel time - auto travel time

ΔC = auto cost - transit cost

X_n = socioeconomic variables

Y is the upper integration limit of the cumulative normal function which actually represents the dependent variable (modal split):

$$\text{Modal split} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Y} e^{-\frac{t^2}{2}} dt$$

Therefore, a change of m units in the function Y has the effect of m standard deviation units in the modal split.

A major difference in the two approaches lies in the use of base trip data for calibration. The marginal utility model studies aggregated trip records to produce interchange transit percentages (a necessary step where hand-fitting of the utility curves was used). The probit analysis used sets of individual sample responses to estimate coefficient values. The latter technique is usually a more efficient method of utilizing data and often provides a structurally sounder basis for analysis of travel behavior.

CALIBRATION AND APPLICATION EXPERIENCE

The two studies utilizing manual curve fitting techniques were carried out by Alan M. Voorhees and Associates, one for

the Southern California Association of Governments in a comprehensive transportation planning study for the Los Angeles area and one for the Twin-Cities Area Metropolitan Transit Commission. In these studies a disutility measure was defined for each mode which converts the various system attributes into time units by using pre-specified weights. Essentially, in-vehicle times were assigned a weight of 1; excess times - waiting and transferring time for transit, terminal time for auto - were assigned a weight of 2.5. Cost was converted into time by a factor equal to one-fourth of the income per unit of time. Transit cost was limited to fare whereas automobile cost was estimated as operating cost (with a higher unit operating cost for CBD-oriented trips) to which was added one-half of the parking cost.

The marginal disutility, U, of transit over automobile was defined as the difference of the two disutilities, namely

$$U = 2.5(T_a+T_w-A_t) + (T_r-A_r) + (F-.5P+aD)/C$$

where:

T_a = walk time to/from transit (min.)

T_w = transit waiting time (min.)

T_r = transit riding time (min.)

F = transit fare (¢)

A_t = automobile terminal time (min.)

A_r = automobile running time (min.)

P = parking cost (¢)

D = highway distance (mi.)

a = automobile unit operating cost (5.7¢/mile for CBD trips, 4.0¢/mile otherwise)

C = cost of time estimated as equal to 0.25 x (annual income/2088 x 60) (¢/mile)

Although it might be implied from the utility equation that if travel times and costs are equal, modal splits by transit and auto are equal (since no constant terms was used), this is an assumption that is neither confirmed by other studies nor supported by the results of the Los Angeles study. The use of

more independent variables in the formulation to reflect both the character of a specific city and certain modal attributes not considered, or at least a constant term, would have avoided this confusion and also improved the model.

Disutilities were calculated for zonal interchanges and "matched" with transit trip percentages obtained in an origin-destination survey to produce a disutility curve. The matching was done using trial-and-error hand-fitting techniques.

Los Angeles (Utility Model)

In the Los Angeles study, the basic information used included transit impedance data developed through network cosing techniques which utilized the HUDTRAN transit planning package. Also required were highway impedances including parking costs obtained from police department records. Trip data information was comprised of survey home-based work trip records for the study area. The disutility value for each trip was calculated using the disutility equation and the trips stratified by level of marginal utility representing a range of about 10 equivalent minutes. The transit modal split was then calculated for each stratification and plotted versus the marginal disutility.

Several variables were further examined. A few values of the excess time factor were tested; no particular reason to use other than 2.5 was found.

The mode choice curves were stratified by three levels of auto ownership. Although sensitivity to auto ownership was fairly high, problems associated with the interdependence of transit service and car ownership and with forecasting that variable led to the rejection of this approach.

A three-curve stratification of income was examined. Although the difference between the curves was not as great as between the auto ownership curves, it was felt that the points on the curves were more internally consistent. This approach was selected for recommendation to be used in the future forecasts.

Several utility routines were prepared in addition to the standard planning programs for making utility and mode choice calculations. These routines also produce several trip and mode choice summaries to aid in the analysis and in curve adjustment.

Regional results for 788 traffic zones showed the following statistics and correlation coefficients R^2 (model trips compared with surveyed trips).

Total transit trips	+ 1.0%
CBD transit trips	+ 0.8%
Transit productions	R^2 = .69
Transit attractions	R^2 = .90

Twin Cities (Utility Model)

A similar procedure was carried out in the Twin Cities study. For 756 traffic zones in the region, the following comparisons between the observed and estimated transit trip tables were produced:

Total transit trips	- 0.2%
CBD transit trips	- 1.8%
Transit productions	R^2 = .88
Transit attractions	R^2 = .97
Transit interchanges	R^2 = .57

Chicago (Utility Model)

As with all binary choice models, more than two modes cannot be analyzed simultaneously and must be handled utilizing a staged or stepwise approach, practically if not theoretically undesirable. In the study done by R. H. Pratt and Associates for the North Suburban (Chicago) Transportation Council, four levels of choice were used:

1. Prime modal split, auto versus transit;
2. Submodal split, commuter rail versus other transit;
3. Submodal split, one noncommuter transit mode versus another; and
4. Access mode split, auto arrival versus bus or walk arrival at a rail station.

The equations used in the analysis took the following form:

$$Y = A + (B)\ (\Delta D)$$

where Y = modal split "standard score", a transformation into the cumulative normal distribution function

where A, B = coefficients

ΔD = transit disutility - highway disutility
$= 2.3(T_a+T_w-A_t) = T_r-A_r + 3.3\ (T_c-A_c)$

T_c, A_c = transit, auto costs. Other variables as above

Trial combinations were tested to produce the parameter weights shown in the equation. Regression analysis was used to estimate the coefficient values (A,B). For the prime modal split choice, the equation produced was the following:

Percent transit (standard score) = 29.2 - 27.6 D

For a ΔD of 0 (transit disutility equals highway disutility), the constant term implies a modal split of about 60 percent. The equation's correlation coefficient R^2 in terms of standard score was about 74 percent. Testing of the model produced the following comparisons between actual and estimated ridership for the study corridor:

Rail and Rapid Transit	+ 1.9%
Bus	- 4.9%

This study attempted to take into account certain characteristics of the commuter rail mode to reproduce its relatively high usage. To reflect the mode's good schedule adherence, wait times were reduced to one-half of the headway. To take into account high commuter rail comfort, all travel time by that mode was multiplied by 0.7.

The relative advantages and disadvantages of the two calibration methods should be noted. Manual curve-fitting techniques, while avoiding problems of standard regression in which modal split percentages can fall outside the range 0 to 100, do not provide any statistical measures of the quality of the fit. (The regression described above, as well as the Lisco work below, avoided range problems by the transformations to the cumulative normal density function.) In addition, the curve can be biased by the analyst who derives it, especially when the data is sparse. This technique may also require a purely subjective extrapolation of the curve for use in forecasting service markedly better than that used as the basis for the calibration.

On the other hand, it can be argued that extensive use of analysts' judgment will provide a more complete, consistent model and, in fact, may be the only method available where good data is lacking. Manual methods also allow the use of multidimensional relationships not restricted to any particular linear or non-linear function.

Chicago (Probit)

In the Lisco study, dummy variables (0-1) were used to take into account sex and family structure. Income and age

were transformed into S-curve relationships appropriate to the probit analysis. The multiple regression analyses done showed high significance for the estimates of the coefficients. Since ridership forecasting was not the purpose of the study, no ridership comparisons were available.

The main findings of the study were the following:

. Modal choices appeared to be rational and consistent.

. Comfort was important in mode selection.

. Transit ridership was not highly sensitive to fare changes.

. Walking time appeared to be an important factor.

Let us record the computational requirements for both the Utility and Probit Models. Although manual calibration is used in most of the Marginal Utility Model's applications, several computer routines have been coded to automate certain parts of the procedure. For these routines, 3 minutes of 370/165 time is reported for each run, where 120,000 interchanges are involved. In his small case study, Lisco reported one-half minute of 7094 for calibrating 8 independent variables and 159 observations.

CONCLUSIONS

The Marginal Utility Model is a modal split model whose relatively simple formulation may make it conceptually easy to calibrate and apply using graphical techniques, although the use of regression analysis could provide a more credible forecasting technique. However, for cases involving multi-modal options, both this model and the probit variation be unwieldy to use and prove difficult to achieve satisfactory results.

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APPENDIX A-6

THE n-DIMENSIONAL LOGIT MODEL

INTRODUCTION

The n-Dimensional Logit Model is an origin-destination modal-split model developed in 1970 by Peat, Marwick, Mitchell & Co. (PMM&Co.). It was first used to predict the market shares of four modes of access to airports in the Baltimore-Washington area. Recently, it was used in a study done by PMM&Co. for the Comprehensive Planning Organization of San Diego County, California. Also, the model was calibrated and applied in the DOT Transportation Systems Center's Dual Mode Study.

THEORY

The Logit Model is one of a class of models known as stochastic disaggregate modal choice models in which individual behavior is modeled, or predicted, by assigning to individuals probabilities of using modes on the basis of mode and user attributes.

Two types of assumptions underly the Logit Model. The first pertains to the general nature of the modal-split problem: (a) the modal split of each mode is between 0 and 1, and the sum of all modal shares equals unity; (b) modal splits are monotonic functions of the independent variables; and (c) if the transportation variables are expressed in units such that the disutility of travelling by a given mode is an increasing (decreasing) function of its transportation variables, then the shares of that mode decreases (increases) when any of its transportation variables increase (decrease) and, all other things equal, those of the other modes increase (decrease). The second pertains to the specific premise postulated to structure the relationship between modal split and the explanatory transportation variables, that is, the ratio of a small change in modal split of a given mode to that of a given transportation variable is proportional to the modal split of this mode and to a linear (homogeneous) function of the modal splits of all modes.

These assumptions lead to a set of partial differential equations of the modal split of the mode m (W_m) with respect to the i^{th} attribute of mode j (x_{ij});

$$\frac{\partial W_m}{\partial X_{ij}} = \begin{cases} - \alpha_{ij}\, W_m\, W_j & \text{if } (m \neq j) \\ \alpha_{im}\, W_m\, (1-W_m) & \text{if } (m = j) \end{cases}$$

where α_{ij} or α_{im} are coefficients to be determined. The solution of these equations for a mode m is the following.

$$W_m = \frac{\exp(\sum_i \alpha_{im} x_{im} + a_m)}{\sum_j \exp(\sum_i \alpha_{ij} x_{ij} + a_j)}$$

where a_m, a_j are mode-specific constants.

The formulation of this model allow flexibility often lacking in modal split techniques; (a) there is no limit on the number of modes; (b) there is no limit on the number of attributes considired for each mode; and (c) the set of attributes for a particular mode may be different from those of other modes.

CALIBRATION

Two theoretical alternatives are available for calibration: simultaneous least squares and maximum likelihood. The latter technique has been developed by PMM&Co. into a proprietary FORTRAN computer program. Data required for this program are in the order of 500 observations of travel behavior of the kind usually obtained from a home interview survey. The use of individual observations for calibration data avoids the problems associated with aggregate-type models which require zonal averages that are highly sensitive to zone size. Experience has indicated that although a reasonably calibrated model can be obtained with fewer than 500 observations, about that number is needed for a high level of confidence. Many more than 500 may not significantly improve the calibration and increases the computer running time disproportionately as well as the data collection effort. The set of transportation variables used may include socio-economic characteristics such as income or age, preferably transformed into appropriate ratings or classes. Subjective variables such as reliability or comfort may also be tested although expreience has shown these to be difficult to work with.

The calibration program runs on any IBM 360 or 370 series machine. A typical run on the 370-155 involving four modes, three variables each, and about 500 observations takes about 2 minutes, or about 20 dollars. A set of criteria for judging the quality of a calibration was established as follows:

- Correct signs on coefficients
- Low standard errors of coefficients
- Logical relative and absolute magnitude of sensitivities
- Ability to duplicate sample modal splits
- Constraints on coefficients minimized
- Consistency of impedance types used between modes

Twenty to fifty calibration runs are usually required to reach a satisfactory end product. If manipulation of the calibration data samples is required, overall calendar time for

the calibration (exclusive of initial data collection) may run into several months.

APPLICATION

No "standardized" application program is available for exercising the calibrated Logit Model equations, although several routines were written specifically for the studies mentioned above. These routines read in forecast year values of the transportation variables for origin-destination pairs and compute forecast year model splits. In addition, some of these compute elasticities and sensitivities as well as statistical measures. Machine running time of these programs is quite small relative to the calibration programs.

Transportation variable coefficients for new (non-base year) modes must be inferred from those of the calibration modes. In addition, the analyst has the flexibility to adjust any of the coefficients as appropriate for the future year model.

The model is sensitive to all transportation variables having non-zero coefficients, the sensitivity increasing exponentially as the magnitude of the coefficient increases. The nature of the Logit formulation results in a mode being most "vulnerable" or most "attractive" when it holds half of the market; a mode's potential of gaining (losing) patronage is minimal when its share is already large (small).

It is believed that behavioral-type models such as Logit can be transferred from area to area with, however, suitable adjustments required for area-specific characteristics. With minor input/output modifications, the model can be made compatible with most other types of models in the urban transportation planning process.

EXPERIENCE

In the Baltimore-Washington airport access study, the four modes used were private auto, rented auto, taxi, and limousine. Total trip time and total trip cost were the final impedance variables selected. The correlation coefficients in the observed vs. estimated trip comparisons were almost all greater than .80.

Results of the San Diego County study are not yet public. Three modes were used in the calibration: auto passenger, auto driver, and bus.

In the Dual Mode study, four base year modes were used: auto, bus, rapid rail, and commuter rail. Variables used were

excess (out-of-vehicle) time, non-excess time, and trip cost. Coefficients for several future year dual mode baseline systems were estimated from the base year coefficients on the basis of comparable modal characteristics.

CONCLUSION

The n-Dimensional Logit Model appears to be a flexible technique that is mathematically appealing, yet not difficult to use or understand. It is especially appropriate when suitable calibration data is available. Its use is also recommended when more than two modes are desired.

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APPENDIX A-7

ECONOMIC DEMAND MODEL

INTRODUCTION

The Economic Demand Model [Domencich, et al], developed by Charles River Associates (CRA), is typical of a direct demand model, where generation, distribution and modal split are carried out simultaneously. The model has its genesis from intercity analysis, and subsequently extended to urban travel (notably a study in Boston). Presently, the software associated with the model is maintained by CRA, and therefore proprietary.

THEORY

The model is founded on economic consumer theory. It identifies the variables determining demand and specifies, directly through functional relationships, the effect of these variables on travel demand. The main variables are: the price of using a given mode, and the prices of competing modes. "Prices" in our context are generalized to include travel times, travel costs and other level of service attributes. The demand for a given mode is negatively related to its own prices and positively to the prices of the competing modes.

Socioeconomic or activity variables are also included in the model since a variable like employment level generates the work trips, and the income/auto ownership levels have definite effects on trip-making. It is assumed that generally, demand is positively related to activity measures.

In trying to understand the economic interpretation of the model, it is helpful to mention the concept of elasticity. Demand elasticity is the percentage change in demand with respect to a percentage change in the "price". For example, it is expected *a priori* that fare elasticity is negative since an increase in fare would discourage ridership. But the "cross-elasticity" with respect to the fares of a competing mode would be positive since passengers would shift from the competing mode to the subject mode in response to the competing mode's fare increase.

The general functional form adopted for the model is as follows:

$$T^{p}_{ijm} = F\ (\underline{A}^{p}_{i},\ \underline{A}^{p}_{j},\ \underline{L}^{p}_{ijm},\ \underline{L}^{p}_{ijn})$$

where,

T^p_{ijm} = the number of round trips between origin i and destination j by mode m for purpose p.

$\underline{A}^p_i$ = vector of activity (or socioeconomic) characteristics in origin zone i appropriate to purpose p.

$\underline{A}^p_j$ = vector of activity (or socioeconomic) characteristics in destination zone j appropriate to purpose p.

$\underline{L}^p_{ijm}$ = vector of the level of service attributes, consisting of travel time and travel cost components, for the round trip from origin i to destination j by mode m for purpose p.

$\underline{L}^p_{ijn}$ = vector of the level of service attributes for the competing mode n.

Four alternative forms of the general equation were tested--all of which can be transformed into a linear (or log-linear) form for statistical estimation purposes:

	Model Equation	Elasticity	Form Estimated
product form:	$T = KX^a$	a	$\ln T=\ln K+a\ln X$
linear form:	$T = K+aX$	$a\frac{X}{T}$	$T = K + aX$
product exponential form:	$T=KX^a e^{bX}$	a+bX	$\ln T=\ln K+a\ln X+bX$
mixed log-linear form:	$T=K+a\ln X+bX$	$\frac{a+bX}{T}$	$T=K+a\ln X+bX$

where,

T = dependent variable
X = independent variable
K, a, b = parameters to be estimated

There are inherent economic assumptions associated with these four forms. The product form implies that the elasticities are constant over the entire range of the variable (i.e., the percentage change in demand with respect to a change in price is the same no matter what the price is). The product form is the single case where the elasticities are equal to the coefficients. All the other forms imply that the elasticity varies continuously as the "price" changes.

APPLICATION

The Economic Demand Model was used in a Boston Study by CRA. In that study, although a formulation was multi-mode, only the binary choice between automobile and a general transit category was analyzed. There were two trip purposes, shopping and work trips.

The following tables show the variables considered in the analysis.

	Auto Work Trips	Transit Work Trips
Activity System Variables		
labor force in the origin	X	X
employment in the destination	X	X
median income in the origin	X	X
number of autos per person in the origin	X	X
Level of Service Variables		
in-vehicle travel time	X	
transit time	X	X
out-of-vehicle travel time	X	
excess time	X	X
line-haul cost	X	
fare	X	X
out-cf-pocket cost	X	
excess cost	X	X

	Auto Shopping Trips	Transit Shopping Trips
Activity System Variables		
no. of households in the origin	X	
no. of persons per household in the origin	X	X
median income in the origin	X	X
no. of autos per person in the origin	X	
density of retail trade employment in the destination	X	X
ratio of employment in personal business in destination zone to that in the origin		X
Level of Service Variables		
in-vehicle travel time	X	
transit time		X
out-of-vehicle travel time	X	
line haul cost	X	
fare		X
out-of-pocket cost	X	

All four of the functional forms have been explored. The mixed log-linear form and the product exponential form were preferred:

mixed log-linear form

$$T^p_{ijm} = K^p_m A_{io} A_{jo} \left(\sum_{w,k} a^p_{mwk} L_{ijwk} + \sum_{w,k} b^p_{mwk} \ln L_{ijwk} + \sum_{l} c^p_{ml} A_l + \sum_{l} d^p_{ml} \ln A_l \right)$$

product-exponential form

$$T^{p}_{ijm} = K^{p}_{m} \prod_{w,k} \left(L_{ijwk}^{a^{p}_{mwk}} \; e^{b^{p}_{mwk} L_{ijwk}} \right) \prod_{l} \left(A_{l}^{c^{p}_{ml}} \; e^{d_{ml} A_{l}} \right)$$

where: w is the running index for the modes

k is the running index for the different time and cost attributes

l is the running index for the activity variables in origin i and/or destination j

Variants of the Economic Demand Model have been used in several other applications. For example, the product form has been used in a short haul air transportation study in Boston [M.I.T./NASA - 1972]. Also, the elasticities estimated by the urban transportation demand study discussed in this review have been used in other cities, such as the San Francisco Bay Toll Crossing Study [CRA - 1967].

CALIBRATION EXPERIENCE

The model was estimated by means of constrained multiple regression analysis. The method of estimation consists of estimating parameters by minimizing the sum of squared deviations as with ordinary least squares but performing this minimization while satisfying certain prescribed signs (i.e., plus or minus) or range of values for the elasticity coefficients. These prespecified conditions are derived from *a priori* information through experience or economic theory. The constrained least squares regression technique used in the Boston study states the problem as an equivalent quadratic programming problems.

Several lessons can be learned from the calibration experience in the Boston study. The statistical estimation results reflect three issues associated with the Economic Demand Model, and the class of direct demand models in general:

(1) One of the implicit problems in the calibration of this type of model is collinearity. Collinearity arises when two independent variables are related to one another, either structurally or spuriously. In the context of the model, the mixed log-linear form, for example, which contains both the logorithm of a variable and the variable itself is intrinsicly

subject to some degree of collinearity. Similarly, the inclusion of, say, both car ownership and income in the set of independent variables may cause some complications, since the number of cars owned by a family is obviously related to the income level of the family. Fortunately, collinearity problems can be bypassed, to a certain extent, by constraining the values of the appropriate coefficients.

(2) It was found that the coefficient of multiple correlation, R^2, (which can be interpreted as the amount of variation explained by the regression) is low -- ranging from 0.35 to 0.63. This is quite a bit lower than the statistical fit commonly obtained in trip generation and attraction regressions. The difference in the R^2 between the direct demand and the sequential demand estimation (UTP) procedures is perhaps not totally surprising, while trip generation and attraction merely estimate the sum-total of origins (O) and destinations(D), direct demand models try to arrive at the O-D interchange by a specific mode in one step. It is therefore unfair to compare the R^2 for the two approaches, particularly before corrections are made for the number of degrees of freedom.

)3) High residual error was found in the Boston study. This implies high uncertainty in the predictions of the effects of changes in the transportation system. Together with (a) the collinearity problem, (b) low multiple correlation, and (c) sampling errors and errors in predicting independent variables, the planner should be cautious about using the hard numbers that come out of the direct demand model indiscriminantly.

Resource Requirements

From the Boston and San Francisco experiences, the following manpower and computer resource requirements were reported (sketchy as the information may be). Aside from the data collection problem, the single most expensive task is calibration. In view of the calibration pitfalls mentioned above, quite a few iterations of the quadratic programming and/or multiple regression runs have to be performed before the model can be remotely called operational. For this reason, after the initial Boston calibration, most of the estimated parameters have been directly used in other cities to avoid calibrations "from scratch".

The original calibration work is proprietary to CRA and not revealed to the public. From other sources [Talvitie - 1971], it was reported that for 13 independent variables and 240 interchanges, one hour of 360/65 time and 6 man-months of effort (exclusive of data collection) were requried.

In the San Francisco Bay Toll Crossing Study, calibrated coefficients from Boston were utilized, and essentially no new calibrations were performed. Two man-months of effort were reported to prepare the data and "plug" into the equations. There were 40-50 zones and 12-16 variables. The computer time required for "plugging" in the values of the independent variables was relatively small.

CONCLUSION

The Economic Demand Model is a good example of a direct demand model which is based on sound economic theory, and as such, serves as an analytical forecasting and evaluation tool. At the same time, it reflects some typical estimation problems associated with this class of models -- viz. collinearity, low multiple coefficient of correlation and high residual error. The validity of the theoretical approach should not be dismissed because of these apparent difficulties, since the concept points to the right direction for future model development.

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APPENDIX B

NETWORK MODELS

APPENDIX B

NETWORK MODELS

APPENDIX B-1

FHWA NETWORK PROGRAMS
(Programs BUILDHR, BUILDVN, SUMPED, LOADVN, CAPRES, SELINK, Others)

Introduction

The most widely used of all the network models now available to the transportation planning profession is the set of computer programs that reside in the Federal Highway Administration (FHWA) Urban Transportation Planning System 360 Battery. Within the FHWA Battery, the programs listed, and briefly described below, perform the major network-related functions.

- Program BUILDHR - processes coded link and node data which describes the attributes of the real-world transportation network into a computer (historical record) representation of that network that is processable by all other programs.

- Program BUILDVN - processes the historical record of the transportation network in order to develop minimum impedance paths through the network.

- Program SUMPED - processes historical record and minimum impedance paths and accumulates along the paths for specified ij pairs various specified attributes of the links in each path.

- Program LOADVN - processes the historical record of the transportation network, the minimum impedance paths, and the ij demand matrix (trip table) so that demand for each ij pair is laid out over the links that form the minimum path between that ij pair.

- Program CAPRES - processes the loaded historical record and updates the travel time on each link of the network based upon a predetermined relationship between capacity and loaded volume.

- Program SELINK - processes the historical record, trip table, and minimum impedance paths to determine trip interchanges that transverse selected links and/or nodes of the transportation network.

In addition to these major programs, there are several others for updating, formatting, and plotting data from the historical record.

Theory

The underlying theory of the network modelling portion of the FHWA Battery is that the travelling public is able to accurately discern which path through the transportation network is the shortest (based upon some attribute or combination of attributes of the network, e.g., time or time/distance) and that this shortest path would then always be used. The program where this assumption comes into play is Program BUILDVN where the minimum impedance paths are built through the transportation network (historical record) using a modified version of the Moore Algorithm. The user can specify whether either of two options, "trees" or "vines," are to be built by the program and whether turn penalties or prohibitions are included in the network representation. The "vines" option differs from the "trees" option only in the fact that a node in the network can be entered more than once during the building of a path or tree. In networks with many turn prohibitions and one-way links, it is suggested that the vines option be selected in order to attain realistic paths.

It is recognized that the assumption that all of the travelling public will be able to make use of a single minimum path through the network between a given origin and destination is not always an attainable one. Therefore, during the loading of the network with ij demand from the trip table it is possible to couple together Program LOADVN and Program CAPRES in such a manner that Program CAPRES updates the travel time on all links in the network after all ij demand has been loaded.

The updating of the travel time can be accomplished through use of the standard FHWA function relating volume/capacity ratio to travel time or through use of a function, or set of functions by link type, specified by the user. In the case of

the FHWA function, the new travel time for the link is calculated from the following formulae:

(1) $T = T_o \, [1.0 + 0.15 \, (V/C)^4]$

where: T = Balance time
T_o = Unloaded (Zero-Volume) travel time
V = Volume
C = Capacity

(2) $T_N = m(T_B) + n(T)$

where: T_N = Next assignment time
T_B = Base time
T = Balance time
m = Base time factor which is user specified (default 0.75)
n = Balance time factor which is user specified (default 0.25)

When a user-specified function or functions is employed formula (1) above is replaced with the following:

(1a) $T = T_o \, (TR_{V/C})$

where: T = Balance Time
T_o = Unloaded travel time
TR = User-specified value corresponding to the calculated V/C ratio

The link time for the next iteration is then calculated as in (2) above.

Once the new link travel times have been calculated, Program BUILDVN is then used to create a new set of minimum impedance paths (which may or may not be different paths; i.e., contain different links) from those previously calculated. Program LOADVN is then used to once again load the paths. This procedure is continued until the oscillation between loaded link volumes is reduced; usually after four or five iterations.

In the manner described above, a form of a multipath assignment is performed. It must be emphasized, however, that, while travel between a given origin and destination is spread

over more than one path through the several iterations, in each iteration the loading is simply an all-or-nothing one.

Calibration

The calibration involved in the usage of the FHWA network programs occurs at two specific points. This first is in the "calibration" of the travel times (or speeds) coded into the network representation (historical record) so as to produce acceptable (to the analyst) initial minimum impedance paths. The second is in the specification of the weights for base time and balance time in the assignment time calculation and, when user-specified functions are used, in the volume/capacity ratio to percent of zero-volume time.

The amount of effort involved in calibrating the travel times can be as little or as much as the network analyst wishes to make it. Experience has shown that about one man-day is required to plot a complete tree trace for a network of from 600-900 zones and 4000-6000 links.

Application & Conclusion

The application of the FHWA Battery of network programs is extensive throughout the United States and the world. These programs are the most widely available and recognized of all in the transportation planning profession. As such they are the mark against which all other programs are matched.

Table 1 presents some typical computer running time for several of the programs. It must be emphasized that the computer time cost of Program BUILDVN is very sensitive to the original coding of the transportation network. Experience has shown that Program BUILDVN will run approximately twice as long under the "vines" option as under the "trees" option, if no turn penalties are coded into the historical record. When turn penalties are coded the "vines" option requires approximately four times as much computer time as the "trees" option without turn penalties.

Table 1

Typical FHWA Network Programs Computer Times

Computer and Configuration	Program	Network Zones	Network Highest Node	Turn Penalties Yes	Turn Penalties No	Trees	Vines	CPU Time Minutes
360/40, 256K	BUILDVN	317	3556		X	X		52
	LOADVN	317	3556					21
	BUILDVN	492	4000		X	X		44
	LOADVN	492	4000					36
	BUILDVN	556	4107		X	X		57
	LOADVN	556	4107					46
360/65, 512K	BUILDVN	996	7000	X			X	77
	LOADVN	996	7000					7
	CAPRES	996	7000					2
370/155	BUILDVN	996	7000	X			X	57
	LOADVN	996	7000					6
	CAPRES	996	7000					3
	BUILDVN	996	7000		X	X		17
	LOADVN	996	7000					7
	CAPRES	996	7000					3

APPENDIX B-2

DCO/TRANPLAN NETWORK PROGRAMS

Introduction

The DCO/TRANPLAN program battery, of which the network programs are a part, is proprietary and available through a licensing agreement between DeLeuw, Cather & Company and Control Data Corporation. The total battery incorporates, in one comprehensive set of programs, the ability to perform transportation planning for both a single mode or a multimodal system. This avoids the interfacing problems that can exist between, for example, FHWA-UTP and UMTA-UTPS.

DCO/TRANPLAN was developed for the Control Data 6600 Computer System and envelopes the ideas incorporated into the earlier CDC 3600 TRANPLAN and HUDTRAN. DCO/TRANPLAN is available at any CDC Data Center through the use of CDC's CYBERNET network of interconnected computer installations and remote terminals.

The DCO/TRANPLAN program battery is a fully integrated, user-oriented one. The use of English-language syntax and uniform function controls are used in all programs. In this way, the need for an agency to maintain specially trained computer personnel is minimized, as transportation planning analysts are able to quickly acquire a working knowledge of the system. The consequence of this "black-box" situation is, however, that the modification of any program to fit the unique needs of a specific application is well near impossible.

DCO/TRANPLAN's highway and transit programs are fully compatible with each other; i.e., input and output modes, thus significantly simplifying the procedures required to conduct integrated, multi-modal system planning. The major functions (programs) used for highway and transit network modelling are enumerated separately below.

1. Highway Network Model

Listed below are the names of, and brief descriptions for, the major functions (programs) used in the modelling of the highway network.

Function BUILD HIGHWAY NETWORK - processes coded link and node data, which describe the attributes of the highway network, so as to produce a computer-processible representation (highway network history file) of the real-world network. Current maximum network size is 3,000 consecutively numbered zones and 16,000 nodes.

Function HIGHWAY SELECTED SUMMATION - processes the highway network history file in order to generate minimum paths based upon a user-specified network attribute (cost, distance, time, other). As the minimum paths are built based upon one attribute, the values for the other attributes may also be accumulated.

Function LOAD HIGHWAY NETWORK - processes the highway network history file and the ij demand matrix (trip table) to build minimum impedance paths based upon a user-specified network attribute and to "lay-out" the demand between each ij pair on the links comprising the minimum impedance path for each in pair. Any of three loading procedures, All-or-Nothing (free-flow, no capacity-restraint), Capacity-Restraint, (100 percent loading), Incremental Loading (with capacity-restraint).

Function LOAD HIGHWAY SELECTED LINKS - performs the same loading as the Function LOAD HIGHWAY NETWORK. In addition to the loaded highway history file, (therefore Function LOAD HIGHWAY NETWORK need not be run), a selected link history file is produced for input to various post-processor functions.

Function STOCHASTIC HIGHWAY LOAD - processes the highway network history file and the ij demand matrix (trip table) to build all "reasonable" paths between each ij pair based upon a user-specified network attribute and to "lay-out" the demand between each ij pair on the links comprising the reasonable paths in a proportional manner. (See Program STOCH reviewed separately elsewhere in this report.)

2. Transit Network Model

Listed below are the names, and a brief description, of the major functions used for the modelling of the transit network.

Function BUILD TRANSIT NETWORK - processes coded link and line data, which describe the attributes of the transit network, so as to produce a computer-processable representation (transit network file) of the real-world network. Current maximum network size is 3000 zones and 6000 nodes. The current maximum number of lines is 255 and the maximum number of nodes per line is fifty.

Function BUILD TRANSIT PATHS - processes the transit network description in order to develop minimum paths for selected (all) origin zones ("i's") to all destination zones ("d's") for use with other TRANPLAN functions.

Function TRANSIT SELECTED SUMMATION - processes the minimum paths contained within the transit path file so as to accumulate summed (skimmed) ij travel impedances from the links comprising the minimum paths as specified by the user.

Function LOAD TRANSIT NETWORK - processes the transit network description, the minimum paths of the transit path file, and the transit passenger ij demand matrix (trip table) so that demand for each ij pair is laid out over the links that form the minimum path between each ij pair.

Function LOAD TRANSIT STATION TO STATION - processes the minimum paths of the transit path file and the transit passenger ij demand matrix (trip table) so as to develop an ij matrix of demand with row and column corresponding to an arrival and departure station, respectively.

In addition to the above major functions, there are several others that can be used for updating, formatting, and special-purpose calculations.

Theory

The underlying theory of the network modelling portion of DCO/TRANPLAN is the same as that governing all single path models; namely that the travelling public can first accurately discern the routing with the least travel impedances (the shortest path based upon a specific attribute or combination of attributes) between origin and destination and, secondly, will then always use this routing. The basic problems with these assumptions have been enumerated in the FHWA Battery Network Model review and in the body of this report. They will not be repeated here.

Within the highway network model, the loading of the highway network can be performed by any of three methods. These are:

- All-or-Nothing (100 percent, free flow; i.e., no capacity restraint) - All selected interzonal highway ij demand is loaded onto the links comprising the one minimum impedance path for each ij pair. This represents a "desire" (free-flow) assignment with no consideration given to the type of links used or the capacity of these links.

- Restraint Loading (100 percent loading) - All selected interzonal highway ij demand is backed onto the minimum impedance path between each "i" and "j." The time on each link in the network is then updated using either the standard FHWA functional relationship between volume/capacity ratio and travel time or user-specified relationships. (Potentially) new minimum impedance paths are then built and 100 percent ij demand again assigned. This procedure can be repeated up to 10 times.

- Incremental Loading (with capacity-restraint) - A user-specified, (fixed for all ij's), percentage of selected interzonal ij demand is loaded onto the links comprising the minimum impedance paths during each iteration. After each iteration, the time on each link in the network is updated based upon the above capacity-restraint relationship. This procedure continues until 100 percent of the ij demand has been assigned, with 10 iterations again the limit.

During Incremental Loading, Function LOAD HIGHWAY NETWORK has the ability of adjusting times based upon the time on the links in the initial (base) condition or based upon the time on the links during the previous iteration of loading. PMM&Co. recommends that the link time in base condition be used so as to maintain consistency with the definition of time in the capacity-restraint relationships. After each increment, the user can expand the accumulated demand on the links to represent conceptually a 100 percent loading before the determination of a volume/capacity ratio for entry to the capacity-restraint relationship(s). As in Restraint Loading, the user may specify the utilization of one-quarter of the time difference between the latest calculated link time and the previous iteration link time in order to dampen any great oscillation in time and consequently loading. PMM&Co. does not recommend this use. Also, the user may specify that "undivertable" demand (specifically that for very short or very long ij paths) be loaded with the first user-specified increment of "divertable" demand on the initial (free or unloaded) network. The Incremental Loading is then applied to the remaining "divertable" demand.

Two rather interesting features exist in both Restraint Loading and Incremental Loading portion of the model. The first of these is that the counted volume can be taken as the capacity during calculation of the increment's volume/capacity ratio (count restraint). PMM&Co. does not recommend this practice. The second feature is that, for links in each Assignment Group, Maximum and Minimum speeds may be specified within which the adjusted speed on the link must lie (after damping, if damp- is used). This is an interesting addition which PMM&Co. has not had an opportunity to become familiar with.

Within the transit network model, the selection of paths (and the subsequent loading of ij demand) is based entirely on minimum time. This essentially means that the following assumptions are incorporated:

(1) a traveller can accurately discern the minimum routing from "i" to "j";

(2) a traveller can make use of this minimum routing; and

(3) a traveller will make use of this minimum routing.

While assumptions (1) and (3) have no different effect; i.e., in terms of being more or less correct, here than they do in the modelling of the more ubiquitous highway network assumption (2) has a rather profound negative effect. The non-ubiquity of the transit system and the less-than 100 percent availability of automobiles for access are accepted facts in the real-world situation. However, the modelling process leads to auto access links often-times forming the access portion of a minimum time path for trips that realistically do not have auto available for use.

A second drawback, dealing with the access portion of the minimum time path, is the restriction of only one access link from a zone "i" to the transit system. Realistically, the transit system is accessed by different access sub-modes (walk, bus, auto kiss-ride or park-ride) by users originating at different points within the same origin zone. This real-life fact cannot be properly accounted for within the existing modelling structure.

Calibration

The calibration effort necessary with DCO/TRANPLAN is essentially the same as with the FHWA or UTPS network models, and depends upon whether the highway or transit portions of the modelling process are being employed. In both cases, however, the actual amount depends upon the experience and to some extent the self-imposed standards of the analyst.

The calibration of the highway model occurs first in the "tinkering" with the coded travel times in the network in order to arrive at "acceptable" minimum impedance paths as shown by selected tree traces. When capacity-restraint is used the actual volume/capacity versus travel speed (time) relationships can also be subject to adjustment through a calibration process. The large, in terms of both time and cost, effort involved has lead PMM&Co. to undertake this calibration process on a small-scale test problem network. The same procedure can also be used for selecting the appropriate increments for incremental loading.

On the transit side, calibration is mostly involved with tinkering with the coded travel times and the weights applied to the various components of total time. Here again, the amount of resources actually expended is quite dependent on the time and budget available to the analyst.

Application and Conclusion

The application of DCO/TRANPLAN's highway and transit network models, as such, is rather limited due to the actual short time of its existence. The highway model, which contains the same theoretical base as the older CDC 3600 TRANPLAN, has been used quite extensively under that name including applications in Boston, Cleveland, and Detroit. The transit model, under the name of HUDTRAN, has had relatively lesser usage but has been used in Detroit among other urban areas.

The highway modelling portion of DCO/TRANPLAN has the same basic weakness as any other single-path model. It does, however, have some intersting minor "fulls" added to it that are somewhat appealing. The transit modelling portion is theoretically weak because of the lack of ability of splitting between access sub-modes.

APPENDIX B-3

UMTA TRANSPORTATION PLANNING SYSTEM
(Programs UNET, UPATH, UPSUM, ULOAD, Others)

Introduction

The presently operational UMTA Transportation Planning System (UTPS) of the Urban Mass Transportation Administration consists of fourteen transit planning computer programs (and documentation) which has been explicitly designed, when coupled with the FHWA-UTP S/360 Battery with which they are compatible, to aid in the long-range planning of urban, multimodal transportation.

At present, UTPS runs on an IBM 360/370 computer and must be executed under the full Operating System/360. The programs are written in FORTRAN IV(H) with some assembly language subroutines. The programs dynamically obtain appropriate core storage at the time of execution. The computer system configuration required for their use is thus a function of the individual program and the size of the user's transit network. A 360/40, with 128K core storage, is the minimum recommended computer configuration.

The existing UTPS can be obtained from either UMTA's New Systems Requirements Analysis Branch or FHWA's Public Transportation Branch. No charge is made when UTPS is provided to a state or local governmental planning agency. Due to administrative policy, all other groups must pay $40 to reimburse the Government for the labor and computer time involved.

As sent, UTPS contains load modules, program documentation, "cataloged procedures," and test data. All are included on a user-supplied magnetic tape (800 or 1600 BPI, 9-track). Source coding is _not_ provided.

The programs of the UTPS are flexible, user-oriented, and adhere to uniform software design standards. They can be successfully used for any size urban area. Beyond this, and extremely important, is the commitment of UMTA to distribute, maintain, and upgrade UTPS on a continuing basis.

Diversing from the presently existing system, it is important to note that, under UNTA's present New Systems Requirements Analysis Program, research and development is now ongoing which is aimed at the continued expansion and improvement of UTPS.

This research and development effort will yield such products as new and vastly improved transportation sketch planning and microsimulation models.

The sketch planning model will allow the planner to carry out studies, at the macroscopic level, of a wide series of transportation system alternatives. At this level it will then be possible to choose only those more promising proposals for more detailed (costly) analysis. The model will place less dependence on massive data bases, coded networks, and, in general, cut down on resource cost. Heavy emphasis is being placed on the use of interactive graphics through use of graphic terminals. This interactive approach promises to be a far more effective means of interfacing the planner/analyst and the computer/model than is found with batch-processing systems.

At the other analytical extreme from sketch planning are the microsimulation models. These models will be able to provide the planner/analyst with information to assist in the detailed analysis of passenger and vehicular flows in and around transit stations and on city streets.

The present UTPS, of which the transit network modelling programs are a part, has as its genesis the set of transit planning programs (the "HUD Package") developed by UMTA when it was part of the Department of Housing and Urban Development. UTPS does not incorporate any new theory beyond that embodied in the HUD package. While traditional in approach, it does still represent one of the state-of-the-art software packages for use in the detailed study of future urban transit systems. Significant improvement in both the functional and operational use of the programs have been made. Programs are more easily executed and less constrained by the host computer configuration.

The names, together with a brief description, of the major programs used in the modelling of the transit network are presented below.

. Program UNET - processes coded link and line data, which describe the attributes of the transit network, in order to produce a computer-processable representation (network description) of the real-world network. Current maximum net-

work parameters are 2000 nodes, 8191 nodes, 3 access (non-transit) nodes, 5 transit modes, 1275 transit routes. The most critical current link-data and line-data constraints are 8 modes and 31 lines per link and 255 lines and 50 stops (nodes) per line, respectively.

. Program UPATH - processes the network description in order to develop minimum ("shortest") time paths for selected (all) origin zones ("i's") to all destination zones ("d's") for input to other transit modelling programs. UPATH also computes an interzonal fare matrix by accumulating fares across its minimum time paths.

. Program UPSUM - processes the network description and minimimum time paths in order to accumulate for specific ij pairs the various specified attributes of the links in each path. These attribute sums represent the components of the total impedance ("disutility") associated with each potential ij demand.

. Program ULOAD - processes the network description, minimum ij time paths, and ij demand matrix (transit trip table) in such a manner that demand for each ij pair is laid out over the links that form the minimum path for that ij pair.

In addition to these four major programs, there are several others for updating, manipulating, and formatting specific data sets.

Theory

The underlying theory of the network modelling portion of the UTPS is, once again as with all single-path models, that the travelling public can; first, accurately discern the routing through the transit network with the least travel imped-

ance (disutility); i.e., the shortest time path; secondly, can make use of this path; and, thirdly, will then always make use of this routing. The problem with this series of assumptions, is that transit networks, particularly the access portions, are not anywhere near as ubiquitous as the highway network and the present availability of automobiles.

The actual implementation of this minimum path selection assumption is performed by Program UPATH, the path-finder program. The criterion used by Program UPATH in selecting the shortest interzonal (ij, i≠j) path is a weighted sum of walking, riding, and waiting times from the various coded links and lines in the network description. The weights used are user-specified input and are intended to estimate the trade-off function of the travelling public. The value for waiting time is "inferred" from the coded line headway information. Riding and walking time values are extracted directly from the coded link-data. Particular mode-to-mode transfers, as well as the total number of transfers, are user-specified parameters of the program.

During demand loading, Program ULOAD is restricted to loading passenger demand to the minimum time paths because each ij path contains only one type of non-transit (access link), only that access type will supply demand to the transit system. This means, in practical terms that automobile access links will invariably supplant bus access link, even though an auto may very well not be available to the transit system user for that access portion of the total ij trip. Walk access also becomes a problem in that zoning size often makes walking the most appropriate access "mode" from some part of the zone and vehicle (whether auto or bus) from the remainder. In this case, the user, through coding and weighting, can have one, but not both.

Calibration

The calibration involved with the UTPS transit network modelling process occurs in the "tinkering" with the coded travel times in the network description and the weighting factors used in Program UPATH. This tinkering is aimed at producing (to the analyst) acceptable minimum time paths.

The amount of effort involved is governed, therefore, by the mood of the analyst. It can be as little or as much as he/she wishes to make it. Past experience with the plot-

ting and analysis of minimum path tree traces has been that approximately one man-day per trace is required for the normal size (700 zones, 4000 links) transit network.

Application and Conclusion

The first release of the UTPS was made in October 1972, which means that too little time has passed for any real applications to have been undertaken. As part of the New Systems Requirements Analysis Program, extensive field testing of the computer programs are now underway. The results of these tests, in terms of computer running time requirements, should start to become available in the next several weeks. (Hopefully, some of this information should be available in time for incorporation into the final version of this report.) The predecessor programs of the HUD Package were quite widely used by transportation planners. From 1967-71, the HUD Package was used to help design scores of transit systems in urban areas throughout the United States and abroad.

The most basic weakness is the assumption of all-or-nothing usage of the minimum time path, particularly as this applies at the access portion of the trip. The less ubiquitous, than highway, characteristics of transit service, especially the availability of an auto to access the system, make this "simplifying assumption" an even more dubious one when applied to transit planning.

APPENDIX B-4

DIAL STOCHASTIC ASSIGNMENT MODEL
(Program STOCH)

Introduction

The subject of this model review is an evaluation of two alternative algorithms, developed by Mr. Robert B. Dial, that are capable of producing a multipath assignment of traffic (demand) to a transportation network based upon program-calculated probabilities of usage of a link in the system by that traffic.[1] These two algorithms entitled, respectively, the Probabilistic Multipath Assignment and the Parallel Probabilistic Multipath Assignment, differ only slightly in their formulation. Only the Parallel Probabilistic Multipath Assignment is presently in an operational state, however.

The reason for the development of a probabilistic multipath traffic assignment model was the need to more correctly model the non-deterministic choice function of the traveling public[2] in a manner that is usable; i.e., economically feasible. It is, in fact, this necessity of economic feasibility that has lead to the implementing of the Parallel Probabilistic Multipath Assignment algorithm under the name of Program STOCH.

While one of the ground rules for reviewing of models in this study is that the model is presently operational, this requirement will be relaxed in this report in order to present the conceptually appealing aspects of the Probabilistic Multipath Assignment algorithm as well as that of the Parallel Probabilistic Multipath Assignment algorithm.

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[1]The model development was carried out under U.S. Department of Transportation Contract FH-11-6972.

[2]It is well known that the basic assumption underlying the assignment of traffic to only the minimum time path between a given origin and destination contradicts actual trip behavior, and undoubtedly would even if the traveling public was able to accurately discern which path through the transportation network was indeed the shortest.

Theory

In order for any probabilistic multipath traffic assignment model to be of any redeeming social value, it must improve on the results produced by other existing operational models (i.e., correct all, or at least some, of their major faults) at a cost commensurate with this improvement in results (i.e., be cost-effective). The following five common-sense functional specifications had been established by Dial as necessary to the satisfying of these goals.

> 1. The model should give all "reasonable" paths between a given origin and destination a non-zero probability of use, while all "unreasonable" paths should be given a probability of zero (quotation marks added).
>
> 2. All reasonable paths of equal length should have an equal probability of use.
>
> 3. When there are two or more reasonable paths of unequal length, the shorter should have the higher probability of use.
>
> 4. The model's user should have some control over the path diversion probabilities.
>
> 5. The assignment algorithm should not explicitly enumerate paths.

Dial further states specifications 1-3 are simplifying assumptions necessary to the selection of routes (paths) within the transportation network, while specifications 4 and 5 are necessary for the model to be considered practical. It should be noted here, however, that specification 4 may or may not be necessary after much-needed research into the traveling public's route selection choice function is carried out. Specification 5 will hold, however, until a generation of electronic computers is developed that is much faster computationally than the present generation or a new path-finding algorithm, which is much more efficient than those presently employed within transportation planning models, is developed.

Definition of Efficient Path

It is evident from the above specifications that, at the heart of the theory, the assumption lies that the term "reasonable path" can be provided with a working definition. Dial states that a path is assumed to be reasonable if it is "efficient." He then proceeds to define an efficient path as one that does not backtrack on itself. He further sets the working conditions for path efficiency to be the following:

1. Parallel Probabilistic Multipath Assignment (Program STOCH)

   An efficient path between nodes "o" and "d" must be composed of only links possessing the property that the initial node of the link is closer to the origin node "o" than is the final node of the link.

2. Probabilistic Multipath Assignment

   An efficient path between nodes "o" and "d" must be composed of only links possessing the following two properties:

   a. The initial node of the link is closer to the origin node "o" than is the final node of the link; and

   b. The final node of the link is closer to the destination node "d" than is the initial node of the link.

It can be seen that the working definition of efficient path in both algorithms shares the common requirement that the initial node of the link is closer to the origin node of the path than is its final node. The Probabilistic Multipath Assignment algorithm, however, has in its efficient path definition the further constraint that the final node of the link must be closer to the destination node of the path than is its initial node.

The dual constraints of the Probabilistic Multipath Assignment restrict the set of paths that are efficient to only those paths that relate symmetrically to the origin and des-

tination nodes; i.e., links which, in the a-to-b direction, are in a path from "o" to "d" are, in the b-to-a direction, also in a path from "d" to "o." This requirement of duality makes it necessary that the assignment algorithm be executed once for each pair of nodes "o" and "d." This requirement, while to be expected, does use considerable computer time in execution. This is due to the necessity of knowing the shortest path length from each node "o" to "d" and, to the algorithm-unrelated fact, that for large study areas, there are many o/d pairs.

The Parallel Probabilistic Multipath Assignment definition eliminates the need to know the shortest path distance from each node "i" to the destination node d. Therefore, the assignment algorithm need only be executed once, with all trips originating at the origin node "o" being assigned to all destinations "d's" simultaneously. This simultaneous assignment to all "d's" has proven to be, computer-time-wise, many orders of magnitude more effective. The cost (consequence), however, is that the definition of an efficient path is considerably less discriminating, resulting in significantly more paths that are now classified as efficient.

Under the relaxed definition of efficient path used in the Parallel Probabilistic Multipath Assignment, a graph of all efficient paths from a common origin node "o" may be described. This graph is called a "bush rooted at "o" by Dial. All and only the links in this graph have the property that their initial node "i" is closer to node "o" than is their final node "j." In the Parallel Probabilistic Multipath Assignment described below, a bush is analagous to the shortest path/tree of an all-or-nothing assignment.

Algorithm Description

The existence of different definitions for an efficient path between the Parallel Probabilistic Multipath Assignment and the Probabilistic Multipath Assignment results in two slightly modified algorithms. These two algorithm descriptions are presented below. The first to be presented is for the Parallel Probabilistic Multipath Assignment, as implemented in Program STOCH.

Parallel Probabilistic Multipath Assignment

The algorithm for the Parallel Probabilistic Multipath Assignment can be described in three major steps.

0. (Preliminaries) To simultaneously assign all demand (trips) from an origin node "o" to all destination nodes "d's," the following four items of information must be known about each node "i":

1. y(i) = the number of trips from node "o" terminating at node "i".

2. p(i) = the shortest path distance from node "o" to node "i".

3. I_i = the set of all links whose initial node is "i".

4. F_i = the set of all links whose final node is "i".

Letting link "e" = (i,j) have the length "t" (i,j), the "likelihood of use" (probability) for each link e can be calculated as:

$$a(e) = \begin{cases} \exp\Theta[p(j)-p(i)-t(i,j)] & \text{if } p(i)<p(j) \\ 0 \text{ if } p(i) \geq p(j) \end{cases}$$

Once a(e) has been defined for each link, the following two-pass process is undertaken. Note that only those links where a(e) is not zero need be considered.

1. (Forward pass) By examining all nodes i in <u>ascending</u> sequence with respect to p(i), their distance from the origin, calculate for each link "e" in "I_i" its "link weight" as:

$$w(e) = \begin{cases} a(e) \text{ if "i" = "o" (the origin node)} \\ a(e) \sum_{e' \text{ in } F_i} w(e') \quad \text{(for all other nodes)} \end{cases}$$

When the destination node "d" is reached, go to Step 2.

2. (Backward pass) Starting with the most distant destination node "d", examine all nodes "j" in <u>descending</u> sequence with respect to p(j). For each link e in Fj perform the following two substeps:

2.1. Assign a trip volume $x(e)$ to each link "x" as:

$$x(e) = y(j)w(e)/\sum_{e' \text{ in } Fj} w(e')$$

2.2. Increase the node volume at "e's" initial node "i" by "e's" link volume as:

$$y(i) \leftarrow y(i) + x(e)$$

When the origin node "o" is reached, stop. The assignment is complete as all trips originating at node "o" have now been assigned.

Probabilistic Multipath Assignment

The algorithm for the Probabilistic Multipath Assignment can also be described as three major steps.

0. (Preliminaries) To assign a demand of "y" trips between origin node "o" and a destination node "d," the following four items must be known for each node "i":

1. $p(i)$ = the shortest path distance from "o" to "i."

2. $q(i)$ = the shortest path distance from "i" to "d."

3. I_i = the set of all links whose initial node is node "i."

4. F_i = the set of all links whose final node is node "i."

Letting link "e" = (i,j) have length $t(i,j)$, the link likelihood for each link "e" can be calculated as:

$$a(e) = \begin{cases} \exp\Theta[p(j)-p(i)-t(i,j)] & \text{if } p(i)<p(j), q(j)<q(i) \\ 0 & \text{all other cases} \end{cases}$$

Once $a(e)$ is defined for all links "e", the algorithm is again described by a two-pass process, which again need only consider those links where $a(e)$ is not zero.

1. (Forward pass) By examining all nodes "i" in <u>ascending</u> sequence with respect to $p(i)$, their distance from the origin, calculate for each link "e" in "I_i" its "link weight" as:

$$w(e) = \begin{cases} a(e) & \text{if "i" = "o" (the origin node)} \\ a(e) \sum\limits_{e' \text{ in } F_i} w(e') & \text{(all other nodes)} \end{cases}$$

When the destination node "d" is reached, go to Step 2. (The reader will notice that Step 1 of this algorithm is identical to Step 1 of the previous algorithm.)

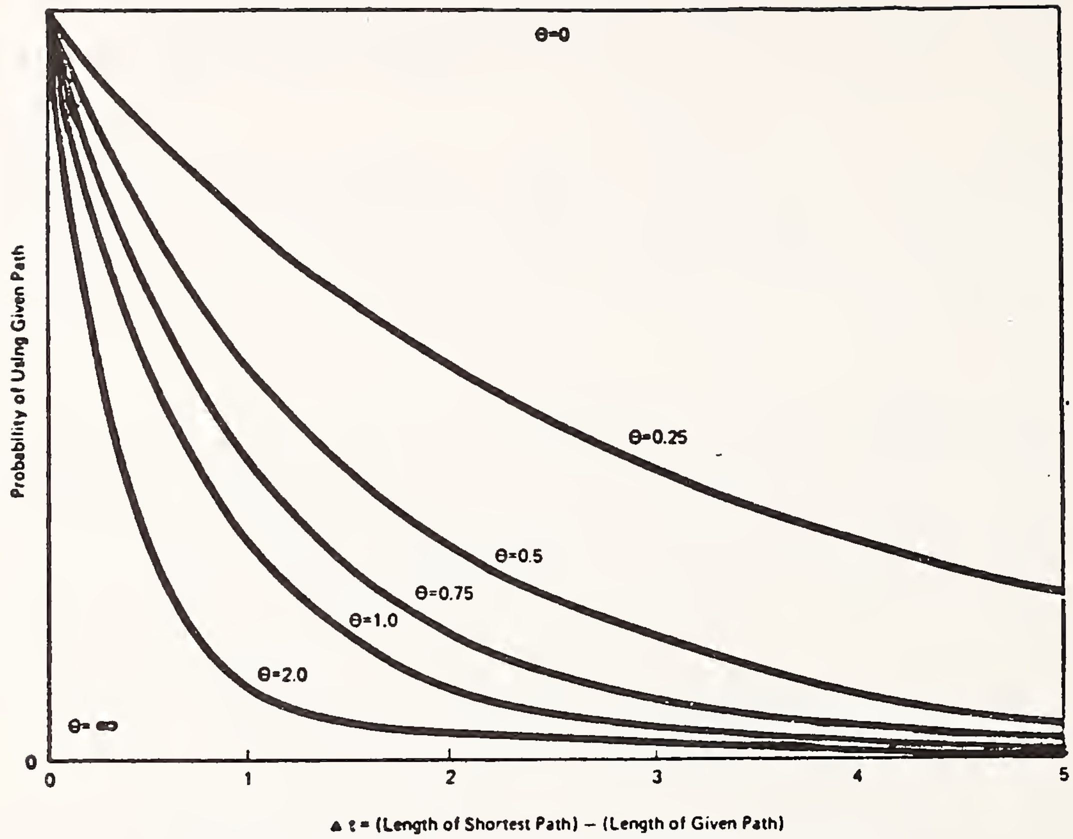
2. (Backward pass) Starting with the destination node "d", examine all nodes "j" in <u>descending</u> sequence with respect to p(j). Assign a trip volume x(e) to each link "e" in "Fj" as follows:

$$x(e) = \begin{cases} y.w(e) / \sum\limits_{e' \text{ in } F_j} w(e') & \text{if "j" = "d" (the destination node)} \\ w(e) \sum\limits_{e' \text{ in } I_j} x(e') \Big/ \sum\limits_{e' \text{ in } F_j} w(e') & \text{all other nodes} \end{cases}$$

When the origin node "o" is reached, stop. The assignment of trips between "o" and "d" is complete. The reader will notice that in the algorithm the functions "x" and "w" are defined recursively. Therefore, the order of their calculation is required to be as specified.

<u>Calibration</u>

The only calibration as such required by Program STOCH is that involved in the selection of the appropriate diversion parameter "Θ", as it appears in the exponent of the link likelihood a(e). As shown in the figure below, as "Θ" varies from zero to infinity, the probability of using a particular path which is Δt longer than the shortest path is directly proportional to exp (-ΘΔt). Thus, as "Θ" increases in value, the likelihood that a trip will use the links making up the shortest path also increases. When Θ is zero, all efficient paths are considered to have an equal likelihood of use. In this case, the topological significance (location) of a link in an efficient path is its sole criterion for attracting trips. At the far extreme, where Θ is large in value; i.e., 10 or greater (Dial); the result is that only links on multiple shortest paths have any likelihood of use. The results is a multiple shortest-path assignment in which trips are assigned to <u>all</u> and <u>only</u> shortest paths. This is the equivalent of



Probability of using a given path Δt longer than shortest path.

Note: The scale of the vertical axis depends on the number and length of competing efficient paths.

an all-or-nothing assignment that appropriately considers parallel routes.

Dial suggests that somewhere between these two useful extremes, there lies a value, or set of values, of Θ that best duplicates the results of human behavior. He suggests that this is a topic for further experimentation; given good route selection data or specific screenline interviews. Until a specific Θ, or set of Θ's, is produced by such research, the network analyst has to "tinker" with the value of Θ, much as he does network times, until the resultant assigned link volumes satisfactorily (to him) duplicate observed traffic counts. The limited amount of "tinkering" that has been done indicates that values between 0 and 0.5 are most appropriate.

Application

The applications of Program STOCH are still rather few. The firm of Alan M. Voorhees and Associates have used their

version (a simplified one) of the program (AVSTOCH) on several assignments in the U.S. and in England. Their most recent use was as part of the Boston Transportation Planning Review for the Boston, Massachusetts region.

Initial results from Program STOCH showed computer running times on an IBM 360/65 that were approximately 1.5 times those for an "all-or-nothing" assignment with the FHWA program package (Programs BUILDVN and LOADVN). Table 1 presents some early computer running times and core storage requirements for different network sizes. The time ranges indicate the effect of selection of different program options.

Table 1

Comparative Computer Running Times
Program STOCH

Network			Trip Table	Computer	
Zones	Highest Node	Number of Links	(includes intras)	CPU Time	Core
74	393	1088	25,193	27- 47 sec	82- 84K
202	1022	2228	228,311	165-212 sec	102-112K
713	3708	9126	1,914,953	2174 sec	194K

Conclusion

Of the two algorithms developed by Dial, the Probabilistic Multipath Assignment, which holds the most theoretical appeal due to its more realistic working definition of an efficient path, is not feasible for use on large transportation networks. The Parallel Probabilistic Multipath Assignment (Program STOCH) algorithm, with its more relaxed definition of an efficient path, does represent a feasible tool for the loading of large urban area transportation networks. As such, it is the only operational multipath (diversion) assignment available. Coupled with a capacity-restraint feature, as it can be with Program CAPRES in the FHWA program package, Program STOCH offers a very powerful assignment tool to the transportation planner.

APPENDIX C

COST-BENEFIT/IMPACT MODELS

APPENDIX C

COST-BENEFIT/IMPACT MODELS

APPENDIX C-1

THE SRI NETWORK ANALYSIS PROGRAMS

INTRODUCTION

SRI undertook the development and implementation of a software package for a fully integrated traffic assignment and evaluation package in 1971. It was designed to be a highly flexible analytic procedure that could be applied to a wide range of transportation problems (persons and goods movements) in large and small cities. The genesis of SNAP was a set of programs developed by the Institute of Transportationand Traffic Engineering (ITTE) at the University of California. The programs are quite analogous to the Federal Highway Administration's (FHWA) Urban Transportation Planning Programs, and Urban Mass Transportation Administration's (UMTA) UTPS, and perform similar functions. The package, however, has several extensions to permit the analysis and evaluation of urban transportation, intercity passenger transportation and freight transportation, by applying separate sets of programs. The programs are proprietary to SRI, who have applied the package on behalf of the States of Michigan and Tennessee for statewide transportation plan evaluation, and in New York City for evaluation of mid-town Manhattan people mover system.

THEORY

The SNAP package, in general, does not incorporate new theories or techniques of traffic estimation than those incorporated in the FHWA and UMTA packages. The basic trip generation, trip distribution, modal split, and trip assignment techniques are incorporated. The overall program structure includes the following:

- Link Analysis
- Path Analysis
- Demand/Modal Split
- Network Loading
- Evaluation

The Link and Path analyses are based on the minimum path algorithm developed by the Road Research Laboratory in Great Britain. The demand or trip distribution program is an iterative process incorporating a choice of gravity model or an exponential distribution formula. The modal split is similar to the n-Dimensional Logit Model. Network loading involves the iterative capacity restraint procedure that incorporates a "critical link" method of adjusting travel times on links as

they are loaded, and in subsequent iterations, removes from the network those links that are loaded to or near their capacity. The evaluation program was developed especially by SRI and provides tables of evaluation measures, generated specifically to provide general information on a wide selection of costable and quantifiable criteria. For comparison of alternative systems involving different levels of demand, a procedure is incorporated to determine consumer surplus calculations.

The calibration programs to determine the various parameters for trip generation, trip distribution, and modal split are separate from the SNAP package. The use of standard purpose multiple regression programs is recommended.

The SNAP package comprises 16 program modules as follows:

- LINKCK - General Link Checking Program
- TRANET - Transit Network Link Deck Generator
- MATGEN - Matrix Generation Program
- TRANPAT - Transit Minimum Path Program
- AUTOPAT - Highway Minimum Path Program
- TRIPGEN - Trip Generation Program
- GRAVO - Trip Distribution Model
- PASDEM - Intercity Passenger Demand Model
- MADISON - Urban Modal Split Model
- NETLOAD - General Network Loading Program
- CAPREST - Capacity Restraint Program
- AUTLOAD - Highway Network Loading Program
- BUSLOAD - Transit Network Loading Program
- CONSURP - Consumers Surplus Program
- EVAL - Passenger Transportation Systems Evaluation
- FREIGHT - Freight Transportation Systems Evaluation

Most of these programs are very similar to the standard FHWA and UMTA packages. The reader is referred to these specific model reviews. However, there are two components of SNAP which make the package unique. They are the network analysis programs and the evaluation programs -- both of which will be discussed below:

Network Analysis

The following programs belong to the network modeling portion of SNAP:

Program LINKCK - processes an input link data deck containing the attribute values for each link, inserts standard attribute values from a standard value table based upon the link's classification, and generates a completed (computer error-free) link-data deck for computer representation of the transportation network.

Program TRANET - processes a transit network link-data deck to prepare link-data decks for several alternative transit systems in a given study area based upon a general network nonfiguration. The output transit link-data deck is the format required by the remaining network analysis programs.

Program MATGEN - processes the link-data card file to find minimum impedance paths based upon any one of four link attributes (cost, distance, time, other). The program outputs minimum path trees and the accumulated total values for any, or all, of the four attributes over the minimum impedance paths. In addition, substitution or addition of minimum path attributes can be carried out.

Program TRANPAT- processes the link-data card file to find minimum time paths and to accumulate access, wait, and transit times associated with links contained within each path. Total time, cost, and distance can also be accumulated along each of the minimum paths for networks involving more than one distinct public mode route.

Program AUTOPAT- processes the link-data card file to find minimum time paths and to accumulate total time, cost, and distance impedance values along each minimum path.

Program NETLOAD- processes the link-data card files by mode (highway and transit) to build vehicle minimum impedance paths based upon the selected link attribute (cost, distance, time) and loads the ij pair vehicle demand (trips from a trip table) onto the links in each of the minimum impedance paths. The outputs are final travel times and speeds calculated on each of the auto mode links. If the capacity restraint program has been used for the auto mode, the updated times and speeds are input to the link-data deck. Otherwise, all trips are loaded on their unrestrained minimum paths and any updating of auto link attributes must be done external to the computer. The network is next loaded (or reloaded) with all zone-to-zone trips, and the zone-to-zone fares and travel times for the transit mode input simultaneously with the loading process. As loading occurs, cost, time, accident, and mileage totals are accumulated by zone of origin for each mode in a form compatible with the network evaluation program.

Program CAPREST- processes the link-data card file and vehicle ij demand matrix (trip table) so as to assign all zone-to-zone trips to the highway network without the overloading (exceeding capacity) of any of the individual links of the network. Minimum time, cost, or distance paths are built, the total ij demand loaded onto these paths, and the link having the largest volume/capacity ratios (V/C) found. If this ratio exceeds a specific value (0.99 is suggested) the deamnd on the critical link is factored to reduce the actual V/C to the specified value. The percent reduction is calculated and the demand on all other links reduced by the same reduction. (This results in the loading representing a fixed percentage of all ij demand.) Link speeds and travel times are then updated to reflect these loadings. All links with actual V/C

exceeding a second specified value (0.95 is suggested) lower than the first are removed, as is the critical link, from the network. (The purpose of removing the additional links is to reduce the number of iterations necessary to load the network, the larger the difference, the fewer the number of iterations required.) The updated link-data deck is then used to build new minimum impedance paths and the remaining portion of the demand is loaded on these paths resulting in a new critical link. This process continues until all demand has been loaded on the network and no new critical links are found.

Program AUTLOAD- processes the link-data deck for the highway network to find minimum impedance paths based upon the selected link attribute. The detwork is then loaded with the highway ij demand (trip table) onto the unrestrained minimum paths. As loading occurs, cost, time, accident, and mileage totals are accumulated and output in a form appropriate as input to the network evaluation program.

Program BUSLOAD- processes the transit link-data card file to find the minimum impedance paths and loads the transit ij demand (trips) onto the paths. As loading progresses, cost, time, accident, and mileage totals are accumulated in a form suitable as input to the network evaluation program.

The basic assumption at the heart of the SNAP network modeling procedure is that the traveling public can discern, and will then use, the shortest path, based upon some chosen attribute or attributes of the network, through the transportation network. The minimum impedance algorithm is that developed by the Road Research Laboratory in Great Britain. As such, there are no new techniques or theories embodied in the programs.

During the loading of the highway network, the possibility of capacity-restraint is available. The procedure followed by Program CAPREST marks an interesting change in procedure and will be described in some detail at this point.

The purpose of Program CAPREST is to load all vehicle ij demand (trips from a highway vehicle trip table) onto an input highway network without overlaoding any of the individual links

in the network. Speeds and travel times on the links are appropriately degraded (adjusted) as the links are loaded. The assumption embodied here is that, in real-world situations, the traveling public adjusts its route selection choice as segments of travel routes approach overload conditions and that no route segment exceeds its capacity for any appreciable period of time. The further assumption is also made that there is sufficient capacity in the highway network to accommodate all of the vehicle ij demand on reasonable routes. While this intuitively holds in the real world, it may or may not hold in the simplified networks used in modeling.

In Program CAPREST, minimum time, cost, or distance paths are built between all zone pairs using as given the link attributes from the input highway link-data deck. The total ij demand is then loaded onto these minimum paths, and the link found having the greatest volume/capacity ratio (V/C) value. If this greatest V/C exceeds a user-specified value (0.99 is suggested), the demand on the critical link is factored downward to reduce the actual V/C to the specified value. The percent reduction in demand on the critical link is calculated and the demand on all other links is reduced by this same percentage. This percent reduction on all links has the effect of loading a fixed percent of all ij demand, determined by the permissible demand on the critical link, onto the network, i.e., an incremental loading.

After this reduction in the demand loadings on each link, the speeds and travel times on the links are updated, using specifid volume/capacity versus speed relationships, to reflect these loadings. All links with actual V/C exceeding a second, lower (0.95 is suggested), specified value are found, and together with the critical link, removed from the network. (The purpose of removing the additional set of links is to reduce the number of iterations required for loading the network; up to a reasonable limit, the larger the difference in the two specified values, the fewer the number of iterations required.)

The updated link-data deck is then used to build new minimum impedance paths between all ij pairs, and the remaining demand, above that already assigned, is loaded onto these paths. This loading again results in a new critical link. The demand on all links is again reduced by the fixed percent calculated from the critical link, the appropriate set of near-critical links removed from the network, and the travel times and speeds appropriately degraded. This procedure is continued until all demand has been loaded onto the network and no new critical link can be found.

Cost-Benefit/Impact Analysis

Evaluation criteria are the guidelines against which the characteristics of alternative networks can be measured and their respective abilities to satisfy community goals and objectives can be determined. Regardless of whether the goals and objectives are common to all communities or peculiar to a specific community, users, non-users, or the operator, the evaluation criteria fall into three classes:

1. Costable--criteria whose nature allows a definite cost figure to be derived for them, e.g., engineering, right-of-way, construction and user costs, demand or usage, etc.

2. Quantifiable--criteria for which a definite cost figure cannot be measrtained but for which some type of caridnal measure can be determined, e.g., number of displaced families and amount of land accessible for different uses.

3. Nonquantifiable (qualitative)--criteria that can neither be costed nor cardinally measured at this time but that can be described and perhaps compared or ordinally measured, e.g., social, recreational, and aesthetic values.

SNAP prepares output reports on typical costable and quantifiable criteria.

The evlauation routines have been designed to work with performance data that are derived from the traffic assignment routines and output several criteria or evaluation measures. In this procedure, a system of criteria measure the degree of which a transportation system improvement attains certain urban goals. The criteria relate to various groups in the community. A typical matrix of groups and criteria is constructed as shown in Figure 5.1-C1.

Constructing the matrix entails a five-step process, as shown below.

1. Specify the groups by which the effects will be stratified.

2. Specify the criteria that will be used to measure the achievement of goals and objectives.

3. Develop measurement techniques to measure the criteria as they impact on the groups.

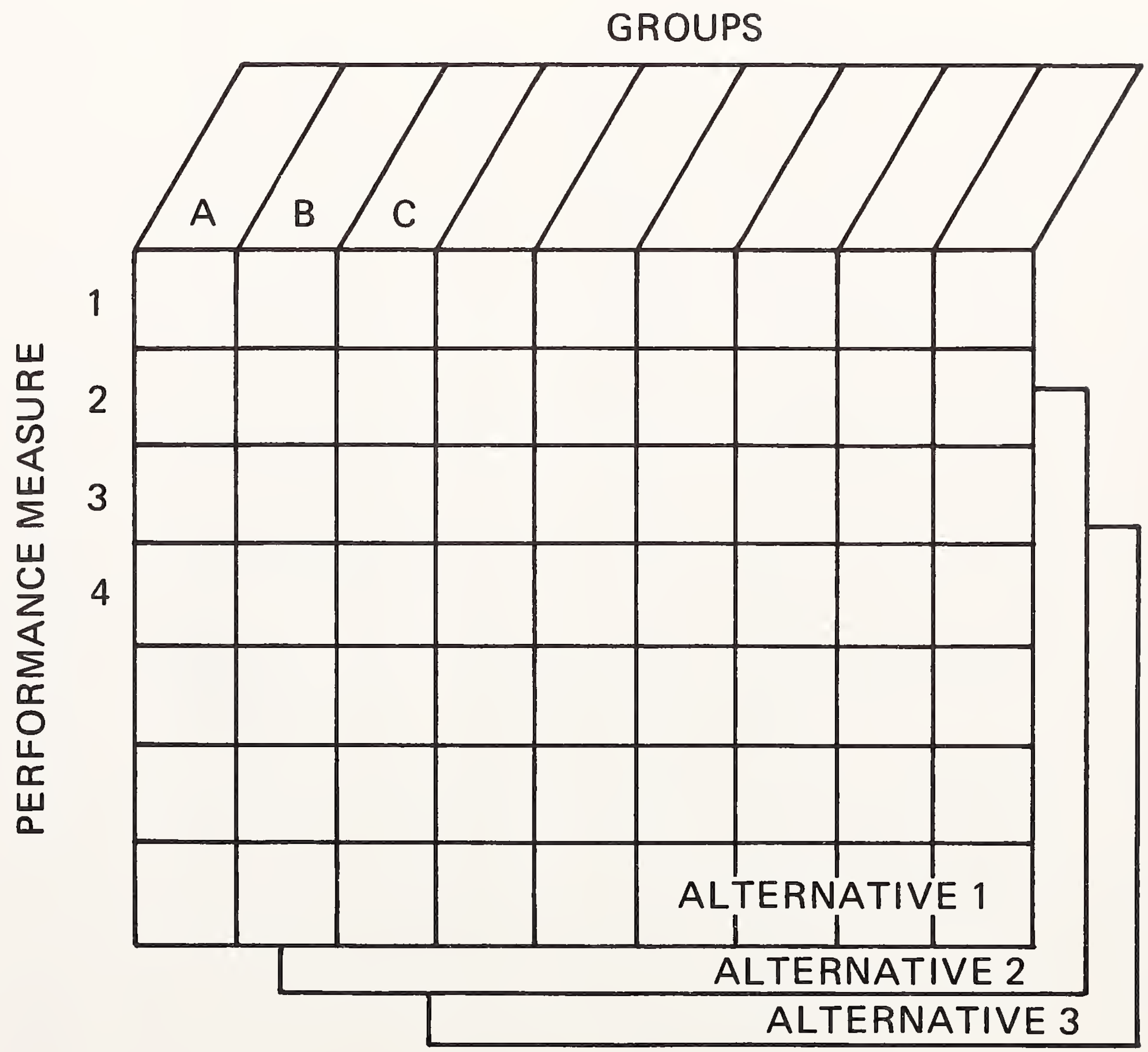


FIGURE 5.1-C1: IMPACT INCIDENCE MATRIX

4. Derive values that will weigh the criteria (as appropriate).

5. Calculate consumer surplus measures.

In SNAP, the cost-benefit/impact analysis is performed in three evaluation programs: CONSURP, EVAL and FREIGHT.

The Consumer Surplus Program (CONSURP) determines the additional user perceived time and cost benefits of an alternative transportation system relative to those of a base case system. Input Data to the program includes number of analysis zones; assumed fixed difference in travel costs between the alternative systems for each zone pair; average speed and variable cost per mile on access links; values of access or local, wait, and transit or line-haul travel times; access, wait, and transit time matrices for the alternative transit systems or local and line-haul (nonlocal) time matrices for the alternative highway systems; and trip matrices for each trip purpose and alternative considered. The access or local, wait, and transit or line-haul time matrices are input as the zone-to-zone time prices for the two alternative systems. The differences in zone-to-zone direct cost prices between the alternative systems are set equal to a constant value plus a variable cost on access or local links. Trip matrices are then input for the alternatives by trip purpose and appropriate consumer surplus measures calculated for each zone pair based on the assumption of linear demand curves. Output Data includes user time benefits (access or local, wait, and transit or line-haul) in both minutes and dollars for each origin zone; user dollar benefits for each origin zone; and summary benefits by origin zone and system totals. (All benefits are measured for the alternative system relative to those for the base case system, i.e., they are the incremental benefits of one system over the other.)

The Passenger Transportation Systems Evaluation Program (EVAL) accepts and manipulates appropriate input data so as to provide, in various output tables, information suitable for evaluation. The Input Data includes the following:

a. System description parameters including an identifier for the system alternative, the time period represented in the study, the number of zones considered, automobile occupancy percentage of vehicle ownership to include in the evaluation report, and other similar factors;

b. Cost parameters such as unit values of time for various modes of travel;

c. Specification of desired zonal groupings;

d. Specification of urban or intercity analysis;

e. Data provided by the network loading program(s) and used in evaluation include auto and public mode passenger miles; traveler cost data totals and traveler time data totals, both by zone or origin and be mode; number of trips by mode, to and/or from each zone within specified travel time intervals (trip time distribution); accident quantities, by zone, by mode and/or facility type, (local street, arterial, freeway), and by severity class (fatal, injury, property damage);

f. Travel time from each zone to each nearest facility type (e.g., hospital) specified; for each accessibility category (e.g., jobs) specified, the number of entities which can be accessed within specified time intervals; air and noise pollution data, parking space requirements data, and selected economic and demographic data.

The passenger systems evaluation program is designed to produce printed output suitable for the evaluation of either urban passenger systems or of intercity passenger systems. The individual criteria utilized for the evaluation of either type system are for the most part identical. Differences appear in the stratification of the criteria and in the fact that the tabulation of community impact criteria (Table 10) is produced only for urban passenger systems analysis.

In general, a two-way stratification--by zonal grouping and by mode--of the evaluation criteria data is produced in each of the output tables. Specification of zone groupings is entirely flexible--some or all zones can be considered, and on an individual or group basis. The table reflecting comfort and convenience is the one table which is not stratified by zone grouping but, rather, is a tabulation of volumes and/or volume/capacity ratios by individual links for each mode.

For urban passenger systems evaluation, data regarding evaluation criteria are developed for the auto mode and for a general public transit mode (which might, in some cases, include more than one actual mode). The exception is the community impact criteria tabulation which is not stratified by mode. For intercity passenger systems evaluation, a four-mode breakdown is specified which includes the auto mode and intercity air, bus, and rail modes.

Tabulations of data suitable for the purposes of evaluation include:

Table	Name
1	Traveler dollar costs (all trip purposes)
2	Traveler time costs (all trip purposes)
3	Traveler cost summary, by trip purpose
4	Traveler cost summary, all trip purposes
5	Safety (accidents/year)
6	Trip time distribution
7	Comfort and convenience (links ordered by volume or volume/capacity ratio)
8	Travel time distribution to or from nearest facility (for various specified facilities)
9	Accessibility (to or from various entities)
10	Community impact, quantifiable criteria (air and noise pollution)
11	Systems Costs (capital, operations, maintenance)

Tables 1 through 7 reflect the impact of transportation systems on the traveler, Tables 8 through 10 represent the impact of such systems on the community, and Table 11 represents the impact of transportation systems on the system operator.

The Freight Evaluation Program accepts and manipulates input data so as to provide information suitable for evaluation purposes for freight systems. The principal inputs are a series of matrices stratified by origin and destination zone, commodity, and mode. Included are matrices on amount of freight, transit time, distance, total cost, and line-haul cost. Other inputs include access tables (time, cost, and distance) from each origin zone to its origin terminal(s) by mode, and a route matrix specifying the path to be used for shipments by origin and destination zone pairs.

Output reports include: tables of shipper criteria; tables of carrier criteria; one or more tables of community measures; and one table of terminal activity.

APPLICATION

There have been three applications of the SNAP to date, on behalf of the States of Michigan and Tennessee and for New York Metropolitan Transportation Authority. The most thoroughly documented application ofthe SNAP model is contained in a series of six reports on An Analysis of Transportation prepared by SRI for the Michigan Interagency Transportation Council (ITC). These reports present the analysis of the sensitivities of evaluation measures to variations in system and performance characteristics for alternative multi-modal transportation systems for the state and urban areas. Report No. 6, entitled "Analysis of Urban Public Transportation Policy" presents a detailed discussion of the application of the model to quantitatively determine the costs and benefits of variations in transit system and performance variables on typical Michigan cities with about 100,000 to 1 million population. The results are being used by ITC to formulate general urban transportation policy at the statewide level of plannign and to assist local urban planners in planning and designing better public transportation systems.

Other applications of the model are underway for the State of Tennessee and New York City-Mid-Manhattan People Mover System Study. Project reports are in process for these applications and are not presently available.

At the present time, the SNAP Battery is proprietary to SRI and is implemented on SRI's CDC 6400 computer. The programming language used is FORTRAN and so the problems of transferal to some other computer system should be minimal. The maximum size problem that can now be handled is approximately a system of 100 zones, 500 nodes, and 1,000 one-way links. The computer running time for the network analysis programs was between 5 and 10 minutes in the Michigan Study. The cost of running all programs through evaluation was $100 for a system of 100 zones, 250 nodes, 800 links and 30 bus routes.

EXPERIENCE

The purpose for which SNAP was designed was to provide a highly flexible analytical process that could be applied to a wide range of transportation planning problems, covering both person and goods movement, in both an urban and an inter-urban setting.

The SRI SNAP package is perhaps one of the few fully integrated Transportation Planning programs available, besides UTPS and DODOTRANS, that permits the execution of the full

package of transportation programs from Trip Generation through to Traffic Assignment with a single set of control cards. Accordingly, the turn-around time between run executions and output reporting is accomplished in terms of hours rather than days. Application costs for less than a 100 zone system are approximately $100 for a single application which is reasonably efficient in comparison with other Transportation Planning packages.

The SNAP package is very similar to FHWA and UMTA packages, with the exception that it has automated the evaluation process. SNAP is the only operational package that outputs extensive evaluation measures for a wide range of costable and quantifiable criteria. Output reports from DODOTRANS and UMTA's UTPS are much more limited and generally produce only the costable measures. The evaluation reports generated by SNAP are extremely effective in conducting comparative transportation system plans. Also, SNAP is the only operational package that has a freight evaluation routine which is very useful in the analysis of freight transportation systems.

CONCLUSION

The SNAP package is an effective technique for analyzing urban transportation, intercity transportation, and freight transportation systems. Its evaluation routines are the most extensive and most versatile of any of those presently available. The network methodology used in combining incremental loading with capacity-restraint is interesting. SNAP is one of the few packages that integrates both network analysis and evaluation in a consistent manner to facilitate the transportation planning process in states and urban areas.

The two primary shortcomings of the package are the limitations on number of zones (100) and the proprietary status of the package. Essentially, only SRI is able to apply the package at fairly aggregate levels of detail. However, recently, the State of Michigan ITC has gained experience in operating the package and have program tapes for their continuing applications.

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APPENDIX C-2

DODOTRANS

INTRODUCTION

DODOTRANS, which stands for Decision Oriented Data Organizer TRansportation ANalysis System, is a computer software package developed at M.I.T. It is primarily an educational analysis tool -- serving as a "breadboard" on which new models and approaches are tested. A large number of models and data processing routines in transportation system planning, ranging from those that address policy making to network assignment, have been or planned to be merged into the package. Through its English-like commmands, DODOTRANS allows users to communicate with the computer in the common terms of the transportation profession, rather than the technicalities of programming languages.

THEORY

DODOTRANS incorporates both modeling and file-manipulation capabilities. The level of sophistication of the models reflects the state of the art. Output data from a model and input data to a model can be stored, manipulated and organized, with little effort from the user, into different groupings/cross tabulations/ stratifications.

The overall structure of DODOTRANS is as follows. A file of transportation "options" is input to the system. "Prediction Models" then operate on the input, yielding a file of "consequences" as output. These output consequencts are again transformed by "evaluation models" into an "impact" file. The user is then provided with the capability of changing the initial transportation option and cycle through the logical sequence of the software once more. In this manner, the user "searches" among alternative options until a choice is finally made.

We will briefly describe the various models and files. Under prediction models, there are:

1. a Network Model -- which performs "incremental" traffic assignment to approximate network equilibrium. The algorithm consists of five basic steps:

   a. Random selection of an origin-destination (O-D) pair;

   b. Determination of the minimum time path between O and D, which constitutes the travel cost between the O-D pair;

c. Use of a demand curve to determine the potential volume between O and D;

d. Addition of an increment of this potential volume to the minimum time path; and

e. Use of a "volume/delay" curve to update the travel times of the links in the minimum time path, due to the increase in volume.

These five steps are repeated until, for each O-D pair, assigned volume first exceeds potential volume determined from the demand curve. Fourteen volume/delay curve sets are used.

2. a "Resource Requirement" Model -- which is a straightforward single link cost model. Total cost is computed from (i) the direct labor, maintenance, overhead, and fuel; (ii) the costs of vehicles and fixed facilities; (iii) the characteristics of the route, the design capacity and expected traffic volume; and (iv) the required amount of fixed facilities.

3. a Demand Model -- which can assume -

   (i) a Baumol-Quandt format;
   (ii) a "conductivity" format
   (iii) a "modal competition product" form; and
   (iv) a "modal competition summation" form

4. a "Demand Shift" Model -- which calculates extremely simple growth calculation as a weighted function of accessibility, present population holding capacity, and an exogenously specified growth rate.

Under "evaluation models", there are a set of straightforward arithmetic and summation operations to convert outputs from or inputs to the prediction models to a file called consequences. Finally, under search models, is basically a manual procedure where the user specified explicitly alternative input options and/or changes in the original options. More sophisticated optimization techniques are planned.

There are three different file structures. (a) In the options input file, the user designates technological, network, operating policy and activity system parameters. (b) In the consequences file, output from the prediction models, information about flow volumes, level of service, resource requirements, and activity system changes are available. (c) Finally,

in the impacts file, the following evaluation measures are computed -- some directly from the input (i.e., subsidy); others from the consequences file:

1. Users -- Measures include (a) total trip time by mode, by origin; by mode; system total; (b)total wait time by mode, by origin; by mode; system total; (c) average travel time by mode, by origin; by mode; system total; (d) average fare by mode, by origin; by mode; system total; and (e) user total cost -- for specified utilities (relative weights of trip time, wait time, and fare) a weighted total cost is computed and aggregated by mode, by origin; by mode; system total.

2. Operators -- Measures include (a) gross revenue from user fares by mode, by origin; by mode; system total; (b) gross revenue from government subsidy by mode; system total; (c) gross payment to government via user tax by mode; system total; and (d) net revenue by mode; system total.

3. Government -- Measures include (a) subsidy to operators by mode; system total; (b) user tax revenues from operators by mode; system total; and (c) net revenue by mode; system total.

4. Functional -- Measures include (a) accessibilities by origin, by mode; by origin; by mode; system total; (b) population change by zone; and (c) income change by zone.

These component and aggregated measures can be used in evaluating such comprehensive objectives as regional growth pattern, income distribution, fiscal feasibility, and political feasibility.

APPLICATIONS

The following represents a typical applicational run of DODOTRANS. First, the user inputs data for the base plan. Second, he defines the base plan and asks the prediction models for the base consequences. Third, he requests selected output from the base consequences. Fourth, the desired evaluation/impact criteria are defined. These impacts are computed and available for user examination. Fifth, the base plan is modified to form an alternative future plan. Sixth, consequences of the modified future plan are predicted, with the impacts computed correspondingly. Seventh, the base and proposed future plans are compared under selected consequences and impact categories. Finally, the user may request a summary of the different input and output files created during the whole analysis sequence.

DODOTRANS has been used to analyze the Northeast Corridor Prototype Analysis and other example problems, including an urban transit corridor and an airport access study.

As of July 13, 1972, the object package of DODOTRANS has been released as a subsystem of the M.I.T. Integrated Civil Engineering System (ICES). The subsystem requires a minimum configuration comprised of a 128K 360/40, two 2311 disk drives or their equivalent, a card input/output device and a printer output device. Copies of the DODOTRANS load modules is available through the Pacific International Computing Corporation, 50 Beale Street, San Francisco, California.

Developed in a university environment, DODOTRANS in its existing status cannot be called a full production system used for large field studies. The major limitation is on the number of one-way network links. The maximum number allowed is 8,191.

Performing traffic assignment is the major part of the computation in DODOTRANS. The run times for incremental traffic assignment is dependent on a number of factors. The more critical ones have been found to be (i) the number of districts, and (ii) the shape of the demand and volume/delay curve (nonlinearities of the curve mean large increases in computing time). On the average,2 minutes of 370/155 is reported for a network with 40 districts.

CONCLUSION

DODOTRANS represents one of the first efforts to integrate a number of the state-of-the-art models and file manipulation techniques under one roof. It is a useful tool to gain insight into prototypical network "equilibrium" problems, with emphasis on policy making and evaluation methodologies. For production runs where refinement is sacrificed for practicality, an alternative computer system may be preferred.

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APPENDIX C-3

TRANSPORTATION RESOURCE ALLOCATION STUDY

INTRODUCTION

TRANS, which stands for Transportation Resource Allocation Study, is a computer software package developed jointly by the U.S. DOT Office of the Secretary (OST) and the Federal Highway Administration (FHWA). It is a policy planning tool geared towards analyzing federal and state transportation improvement programs. A high level of data aggregation is used wherein urban areas or large subareas are treated as basic anlaysis units. The analysis procedure, though macro in nature, relates transportation investment policies to their cost/benefit implications and external impacts.

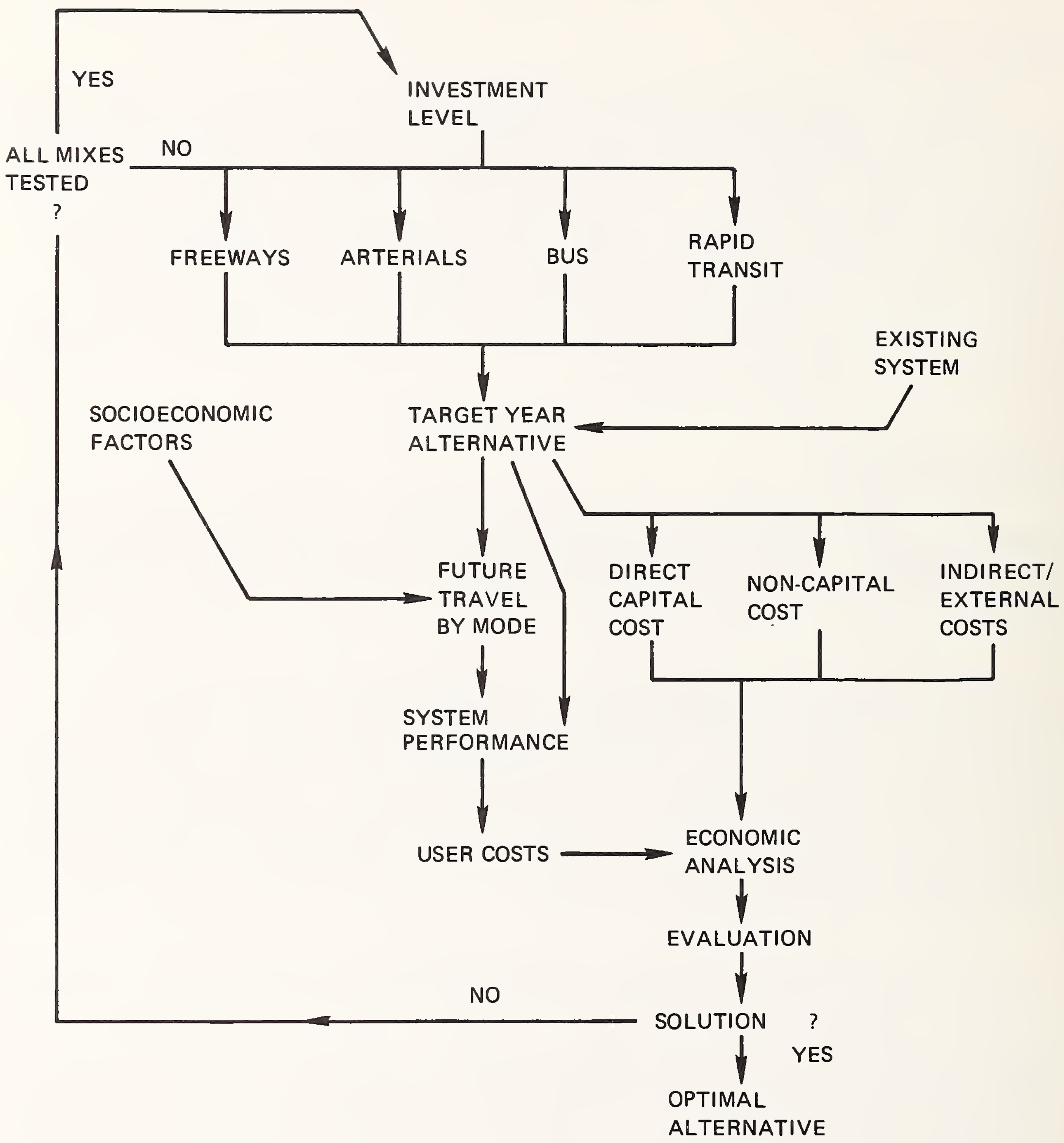
MODEL STRUCTURE

The model has been recently extended to handle multimodal planning since the early days when it was mainly designed for highways. The discussion here pertains to this latest, evolving status of the software package, rather than its former versions.

The best way to describe the TRANS system logic is by reference to the accompanying flow diagram. Let us say an analysis is carried out for an average urban area. First, alternative levels of investment (possibly with an incrementing structure) is specified for the study area. For each investment level, different mixes of freeways, arterials, bus and rapid transit are explored. Each modal mix constitutes a target year plan, which is expressed in terms of system mileage and vehicles instead of fully coded networks.

Second, the target year travel demand is projected by using (i) the travel projections submitted by the states directly; (ii) a modification of the states' projections by system sensitive adjustment factors; or (iii) a set of sequential steps, whereby future demand is related to the transportation "supply". Modal split is performed through the iterating application of a family of curves. The modal split curves are sensitive to travel time and cost and are stratified by trip purpose and by time of day. Other submodals have been developed in order to forecast travel by time of day, direction of travel, facility type (e.g., freeway vs. arterial), and transit submodes.

Third, the projected travel demand is then distributed over the future transportation supply, yielding a specific level of system performance (such as speed) which is turned into



LOGIC FLOW DIAGRAM OF TRANS

dollars of user costs via statistically compiled relationships. A breakdown of user costs is given below:

private vehicle:
- travel time costs
- vehicle running costs
- accident costs
- parking costs
- gas tax

public transportation:
- travel time costs
- fare
- accident costs

Other transportation costs such as direct capital costs, non-capital costs and indirect/external costs are estimated directly from the system supply. An enumeration of these costs follows:

Direct Capital Costs:

- highway
  - new construction of freeway/arterials
  - reconstruction of freeway/arterials

- transit
  - rolling stock (bus, rapid vehicles)
  - guideway for rapid system
  - stations and terminals for rapid systems
  - yards and shops

Non-Capital Costs:

- operating costs

- maintenance costs

Indirect/External Costs:

- fatalities

- land consumption

- dislocation of households and businesses

- air pollution by pollutant

- energy consumption

It is recognized that certain cost items, especially in the last category, are noncostable, i.e., nonquantifiable in terms of dollars.

Fourth, and finally, an economic analysis and an evaluation are performed based upon the costs obtained from the last step. An economic efficiency concept is used. A total value indicator is defined to represent the sum of the prices which all travelers are willing to pay. Total transportation cost is computed by summing up capital, operating and user costs. The difference between total value indicator and total transportation cost constitutes the net value indicator, which is a measure of "consumer surplus" benefit. Noncostable impacts are formulated as constraints in the evaluation procedure. Unless an investment alternative satisfies the constraints, (e.g., maximum number of facilities), it is rejected irrespective of its economic viability.

APPLICATIONS

TRANS is designed as a sketch planning,fast turnaround, tool for analyzing nationwide, multiregional policies. Toward this end, three different "standard" sets of curves have been calibrated in the highway version -- one for the urban area with over 50,000 population; another for small urban areas grouped by states, with 5,000 to 50,000 population; and, the final one is for "rural" regions which analyzes a whole state or a large portion of a state. These three versions of the model are respectively labelled: (i) TRANS - urban; (ii) TRANS - small urban; and (iii), TRANS - rural. In the current multi-modal version, only TRANS-urban is available.

TRANS has been used in a number of studies within DOT. It was used in an analysis of urban highway public transportation facility needs, documented as a report of the Secretary of Transportation to the U.S. Congress. The analysis indicated that busways, special fringe parking facilities and operational improvements can substantially improve public transportation service. The investment fundings needed to achieve these improvements were given. The analysis examined 65 urbanized areas.

TRANS was again used by FHWA to look into the effects of varying policies and assumptions on national highway requirements. A wide range of alternatives ranging from building nothing to extensive highway construction are analyzed under varying patterns of population, mode choice, economic assumptions and impact valuations.

Finally, TRANS was used for the "1972 National Transportation Report" performed by the Office of the Assistant Secretary for Policy and International Affairs. The effects of three

program funding levels, with four allocation of funds among highways and public transportation for each program, were analyzed. The study examined 63 urbanized areas that will have a 1990 population of 500,000 or greater.

TRANS is coded in FORTRAN IV. The unimodal version has been implemented on an IBM 360 machine, requiring about 125K bytes of core. The multimodal version, under the final stages of development, is reported to occupy 220K. A run-time of about 40 minutes on the model 65 is needed to process the 261 individual urban regions, 150 small urban groupings, and 80 rural areas evaluating about 75 transportation alternatives in each. Computer costs are therefore in the range of 1 cent per alternative analyzed.

Developed as an in-house analysis tool, TRANS is not distributed openly in the public domain. However, TRANS has been made available outside the in-house staff for a number of studies, especially when the study has some significance in national policy making. Additionally, a version is currently under development for application by urban transportation studies which will treat individual communities within the area as analysis units.

CONCLUSIONS

TRANS is an aggregate model designed to provide fast turn-around answers to national policy type questions. The usefulness of such a model in FHWA or OST has been deomontrated by the various studies cited in this review. However, because of the aggregate nature of the model, its analysis is not currently designed to pertain to individual cities. While supply data are inputted by city, many of the functional relationships have been calibrated using nation-wide data by population group for urban, small-urban and rural-areas. As such, TRANS does not completely distinguish between City A vs. City B as long as they fall into the same population categorization. TRANS is a sketch policy planning tool and should not be therefore regarded as a substitution for the more detailed micro planning models. Rather, the macro and micro models should be applied in conjunction to supplement each other.

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APPENDIX D

LAND USE MODELS

APPENDIX D

LAND USE MODELS

APPENDIX D-1

THE PROJECTIVE LAND USE MODEL

INTRODUCTION

The Projective Land Use Model ("PLUM") was developed by Dr. William S. Goldner at the Institute of Traffic and Transportation Engineering, University of California, Berkeley, to provide land use allocations and small-area forecasts of population, numbers of dwelling units and employment for use as input to the transportation planning activities of the Bay Area Transportation Study Commission (BATSC). The model is a direct descendant of the original "Model of Metropolis" developed by Dr. Ira S. Lowry for the Pittsburgh Community Renewal Program in 1963. The model has been applied for a variety of different purposes in the San Francisco Bay area, including the generation of small-area activity forecasts for the Bay Area Transportation Study Commission and its successor agency, the Metropolitan Transportation Commission, the evaluation of the potential regional economic impact associated with alternative airport plans and alternative shoreline control policies and as a tool for detailed, small-area analysis with the Marin County. In addition, the model has been calibrated and applied at a regional scale for the San Diego region of California. More detailed descriptions of the model and its history of application than those presented here are given in Rosenthal (1972), Lowry (1964), Goldner (1968 and 1971[a]), and Luken (1971). The best single description of the model is presented in Rosenthal; Goldner (1971[b]) provides a concise summary of the model's relationship to the original Lowry formulation.

General Description

"PLUM" is designed to yield projections of the future small-area (i.e., zone level) distribution of population, employment and land use within an urban area based upon information on the distribution of these characteristics in some base-year, coupled with a series of simple and intuitively appealing allocation algorithms.

These algorithms are based upon two fundamental concepts. The first of these relates to a distinction between "basic" and "population-serving" employment, and the second employs the notion of a spatial "allocation function". Both concepts derive directly from the original Lowry model.

"Population-serving" employment is that for which a local market or service area may be identified based upon the location of the households which it is intended to serve. Typical examples might include retail stores, schools, and the bulk of local government activities. "Basic" employment includes all other employment activities - that is, all that employment whose location is relatively less dependent upon the precise location of households within the urban region both rather on other factors such as proximity to transportation facilities, space availability, agglomeration economies, etc. Typical example of this latter category might be major industrial activities, regional service activities, etc.

"Basic" employment is located exogenously prior to the operation of "PLUM". A series of three spatial allocation functions are then used to distribute the remaining "population-serving" employment and households around these "basic" employment centers. This process proceeds in three steps:

1) An initial set of <u>households associated with persons employed in "basic" employment activities</u> are distributed with respect to the exogenously specified locations of "basic" employment;

2) <u>"Population-serving" employment</u> is then distributed with respect both to this initial distribution of households and to the previously specified locations of "basic" employment; and

3) Finally, a second set of households associated with persons employed in "population-serving" employment activities are distributed around those latter employment locations.

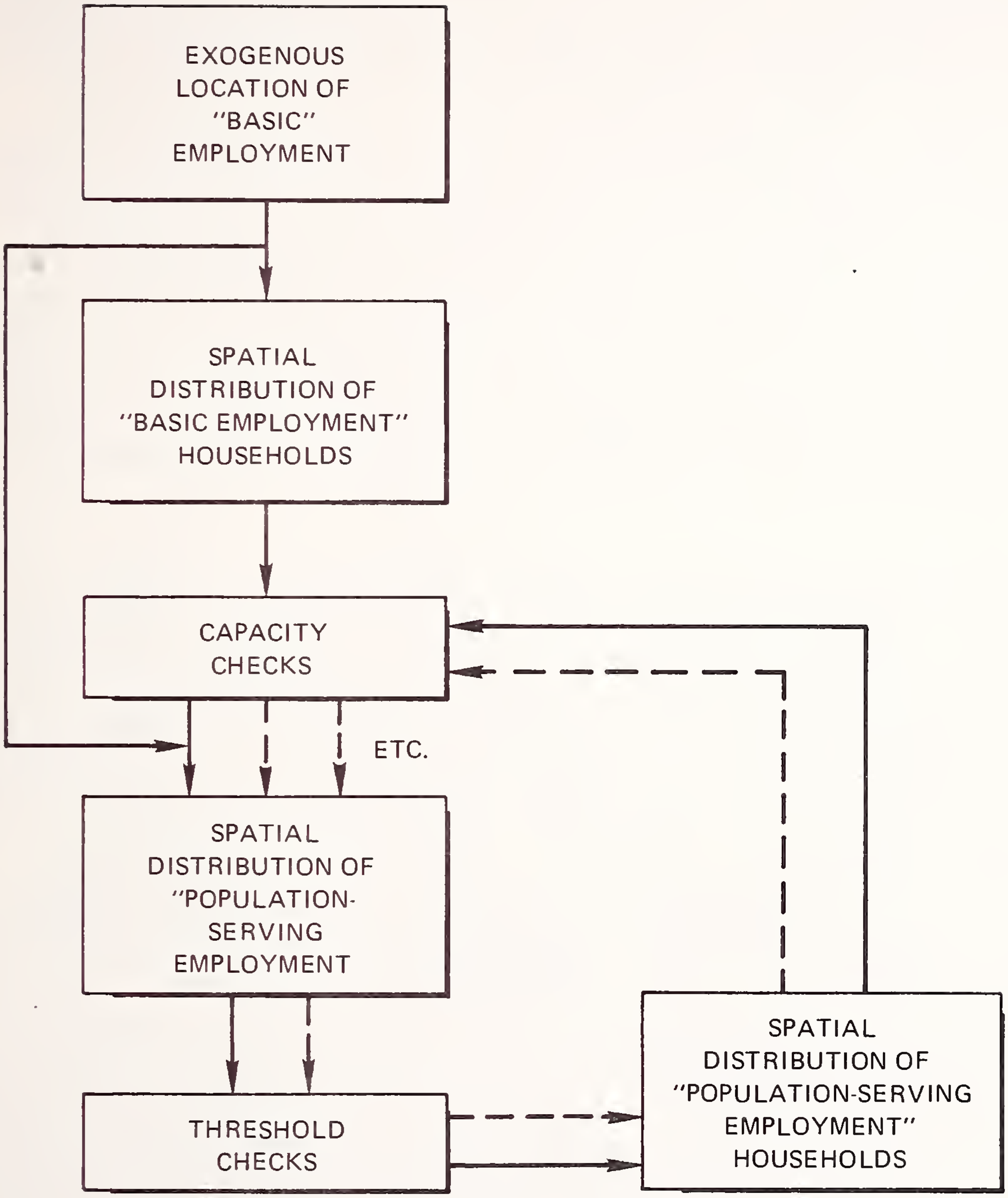


FIGURE 5.1-D1: ILLUSTRATIVE STRUCTURE OF "PLUM"

The allocations in each case are based upon simplistic descriptions of the spatial relationships between the activities involved, based primarily on existing, base-year trip-making behavior and transportation networks. Three separate sets of allocation functions are developed for "work-to-home" (steps #1 and #3 above), for "home-to-shop" (step #2) and for "work-to-shop" (step #2). Each function takes the general form illustrated in Fig 5.1-D2. In the case of the "work-to-home" function, for example, the ordinate represents the probability of a worker locating his residence at a given time (or distance) from his work place. These functions are calibrated in part from inter-zonal travel-time matrices derived from conventional transportation network analysis and in part from considerations of each zone's potential "attractiveness" as a location for the activity being distributed. In the case of population, for example, this "attractiveness" is represented in terms of the residential capacity of the available vacant land.

For any given year, the model iterates to a single, equilibrium solution, based upon the achievement of balance between the initial exogenously specified location of basic employment and the resultant distribution of population-serving employment and the set of households associated with both employment categories. These allocations are subject to a set of constraints, including an upperbound capacity constraint for households within each district, a minimum threshold constraint for the size of population-serving employment and a set of land-consumption constraints reflecting the manner in which vacant land is consumed by development. The result is a final, internally-consistent set of small-area projections of employment, population and land use by small-area for a given target year. For purposes of forecasting over a series of time intervals the model is applied recursively, with the outputs for each forecast-year serving as the base for the next set of forecasts. The outputs of the model include basic estimates of zonal-level households, population, "population-serving" employment and land use for each forecast-year.

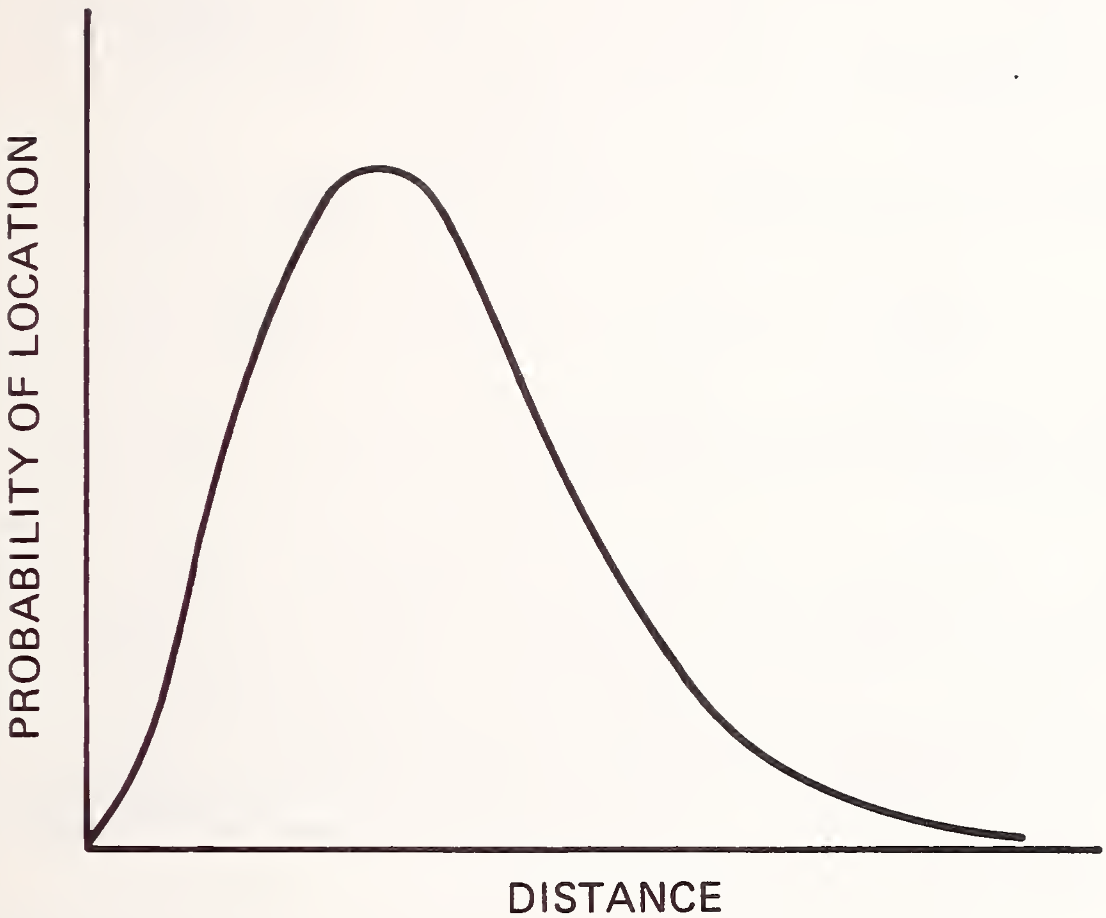


FIGURE 5.1-D2: GENERAL FORM OF SPATIAL ALLOCATION FUNCTION IN "PLUM"

These estimates may be further disaggregated functionally if desired by means of a series of submodels to provide estimates of their component characteristics, e.g., estimates of the distribution of households by income broken down according to nine income classes, etc.

MODEL STRUCTURE

"PLUM" consists of a set of twelve basic programs, including a central executive routine, supplemented by a series of data analysis and data display routines.

The model is divided operationally into four separate phases. These are illustrated conceptually in Figure 5.1-D3.

The initial phase (identified as Phase 0 in Fig 5.1-D3) is concerned with the assembly of the basic set of base-year input data, forecast controls and the calculation of a series of coefficients. The inputs include base-year values of population, number of housing units, number of employed residents, household income and "basic" and "population-serving" employment for each small-area, together with parallel small-area data on land use, broken down into such categories as residential, commercial, industrial, vacant, streets and highways, and unusable, etc. Forecast-year inputs include region-wide projections of total population and employment, projected increments in "basic" employment by small-area and a set of projected, forecast-year inter-zonal travel times for use as input to the calculation of the spatial allocation functions.

A set of coefficients are then calculated from these data. These include a series of base-year land-absorption ratios for "basic", "population-serving" and "residential" activity (e.g., residential land use acreage per household, etc.); the ratio of the number of employed residents to the number of households, the ratio of total population to employed residents and the average household size for each zone. In addition, a series of adjustments are also made in this phase to the base-year data set as necessary to maintain internal consistency and to reconcile the data set with exogenous control totals.

The second phase (identified as Phase I in Fig 5.1-D3) is concerned with the basic allocation function of the model. First, a set of "work-to-home" allocation probabilities are calculated.

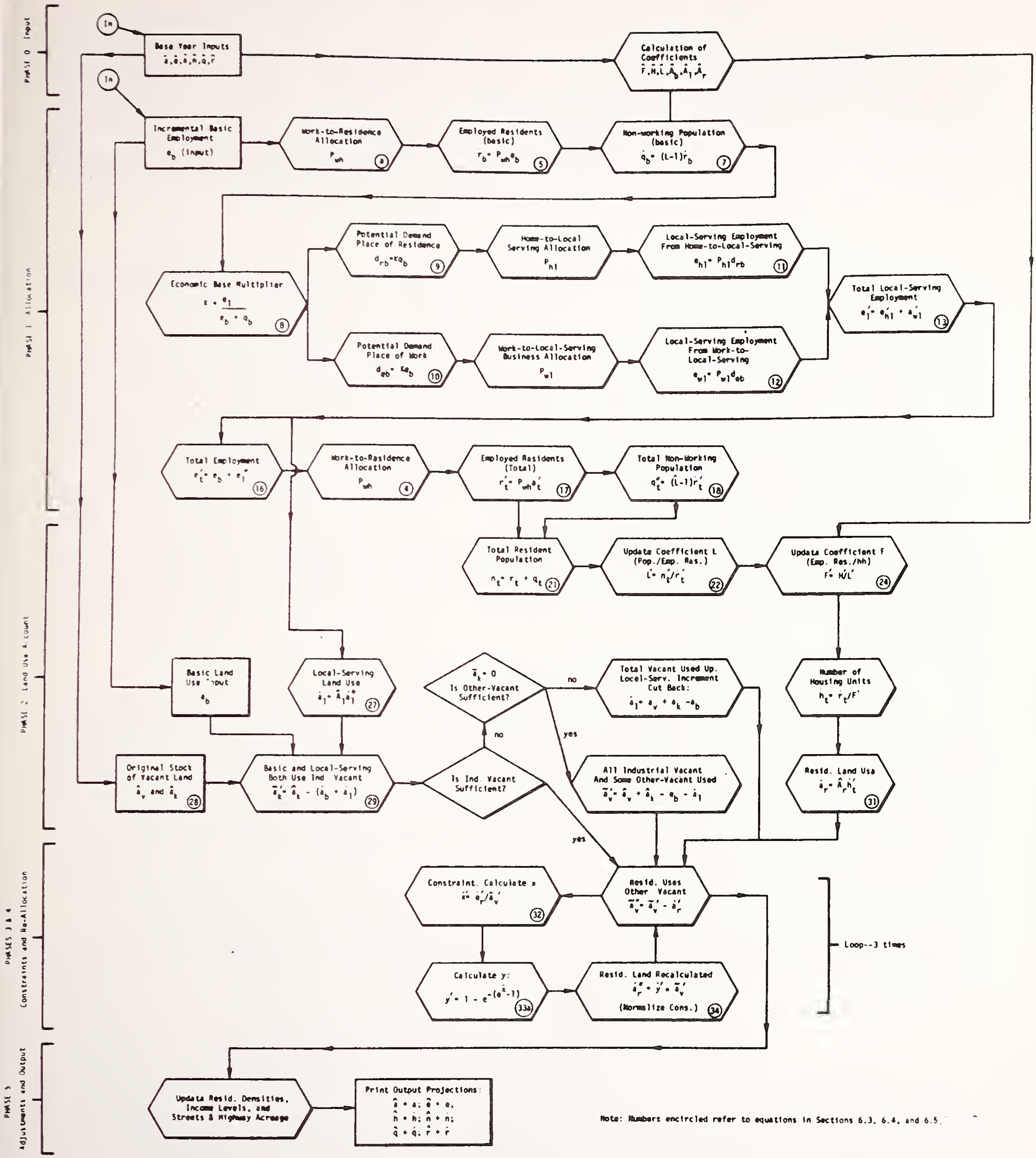


FIGURE 5.1-D3: GENERAL STRUCTURE OF "PLUM"

EXTRACTED FROM ROSENTHAL [1972] (VOL. I, PAGE 8)

These are then applied to the forecast values for the increment in "basic" employment for the forecast interval and a set of vectors of employed residents are generated and summed by zone. These in turn are used to generate estimates of non-working population for each zone which provides the foundation for estimating the demand for "population-serving" employment.

This demand, distributed by means of the home-to-shop allocation function is then combined with the parallel demand for "population-serving" employment generated with respect to the exogenous location of "basic" employment using the work-to-shop allocation function. These demands are summed by zone to provide an estimate of total "population-serving" employment for each small area at the end of the forecast interval. This is then added to the exogenously specified increments in "basic" employment for each zone to provide an estimate of total small-area employment at the end of the forecast interval. At this point the work-to-home allocation function is again used to allocate total employed population for each zone. These estimates in turn are then used as a basis for calculating additional increments in non-working population, total resident population and housing for each zone.

The third phase (identified as Phase II in Fig 5.1-D3) is concerned with land use accounting. The land absorption ratios computed during the first phase are used to estimate the acreage of land of each type required within each zone by the projected increments in "basic" and "population-serving" employment and households. Household activities are allocated initially to land identified as being "industrial vacant" until such land areas are totally depleted. It is then allocated to land designated as "other vacant". Housing is allocated solely to "other vacant" land. The results of these unconstrained increments, including acreage deficits reflecting zonal overflows are then summarized on a printed report.

The next phase (Phases III and IV on Fig 5.1-D 3) involves application of constraints to those areas having on over-allocation of activities and land and to the subsequent re-allocation of the overflow among other zones. This process is repeated iteratively until the total overflow is less than 1%. A further summary is then prepared of the constrained activity allocations for each zone.

The final step in the operation of the model (Phase V in Fig. 5.1-D3) involves the addition of the constrained incremental allocations of activity for the forecast period to the original base-year levels, creation of updated estimates of residential densities, income levels, streets and highway acreage, etc. and the preparation of a final, printed report and an output data file. This file then serves as the basis for input to the next iteration of the forecast cycle.

APPLICATIONS

The model may be employed at varying levels of geographic and functional detail. It has been applied successfully for both relatively coarse-grained and fine-grained area systems. The zonal system in the case of the San Diego application, for example, included some 636 zones. In the case of the application of the model to Marin County, 17 of the original regional-level zones incorporated within the BATSC study were subdivided into a set of 317 sub-zones. The basic outputs of the model, as noted earlier, may be broken down into a more detailed set of component characteristics by means of a variety of submodels. To date, such submodels focus primarily on further disaggregation of employment and household categories, on the estimation of future land values and tax revenues, and on the disaggregation of housing projections into single- and multi-family units. In addition, the analyst has a significant degree of flexibility in terms of his specification and calibration of allocation functions and in the manipulation of land use information to reflect particular land use constraints and development controls. Further developmental work is currently in progress at the Institute of Traffic and Transportation Engineering on expanding the set of outputs generated by the model.

The entire set of programs making up the model system are written in FORTRAN. The program includes some 2000 FORTRAN cards. The model is fully operational on both IBM 360 and CDC 6000/7000 hardware. In addition to a flexible set of tabulation routines, the model outputs may also be displayed by means of a variety of printer and line-plotting routines. These include standard SYMAP computer maps, travel time maps summarizing the travel time from a selected point to all other points within the region (a special program entitled "TRING" is available as part of the "PLUM" package to perform this function) and a variety of histogram plots. The full model system was developed under Federal sponsorship and is in the public domaine. The programs are available either as part of the U.S. Department of Transportation, Federal Highway Administration's urban transportation planning battery or directly

from the Institute of Traffic and Transportation Engineering, University of California, Berkeley.

Data Input Requirements and Output Capabilities

The data input requirements and output capabilities of the model are described in detail in Rosenthal (1972). The input requirements include detailed, small-area population, employment and land use data assembled for a fiven base year, together with information on base-year inter zonal travel times, projected increases in small-area "basic" employment levels for each forecast-year, inter-zonal travel time matrices for each forecast-year, and regional population and employment control totals for each forecast-year. In addition, if constraints are to be imposed upon the use of particular areas of land within the forecasting process, these need to be identified in advance.

The basic set of outputs of the model include small-area estimates for each forecast-year of:

- Total housing units
- Total resident population
- Group quarters population
- Total number of employed residents
- Total non-working population
- Total employment
- "Basic" employment
- "Population-serving" employment
- Total population
- Total land area

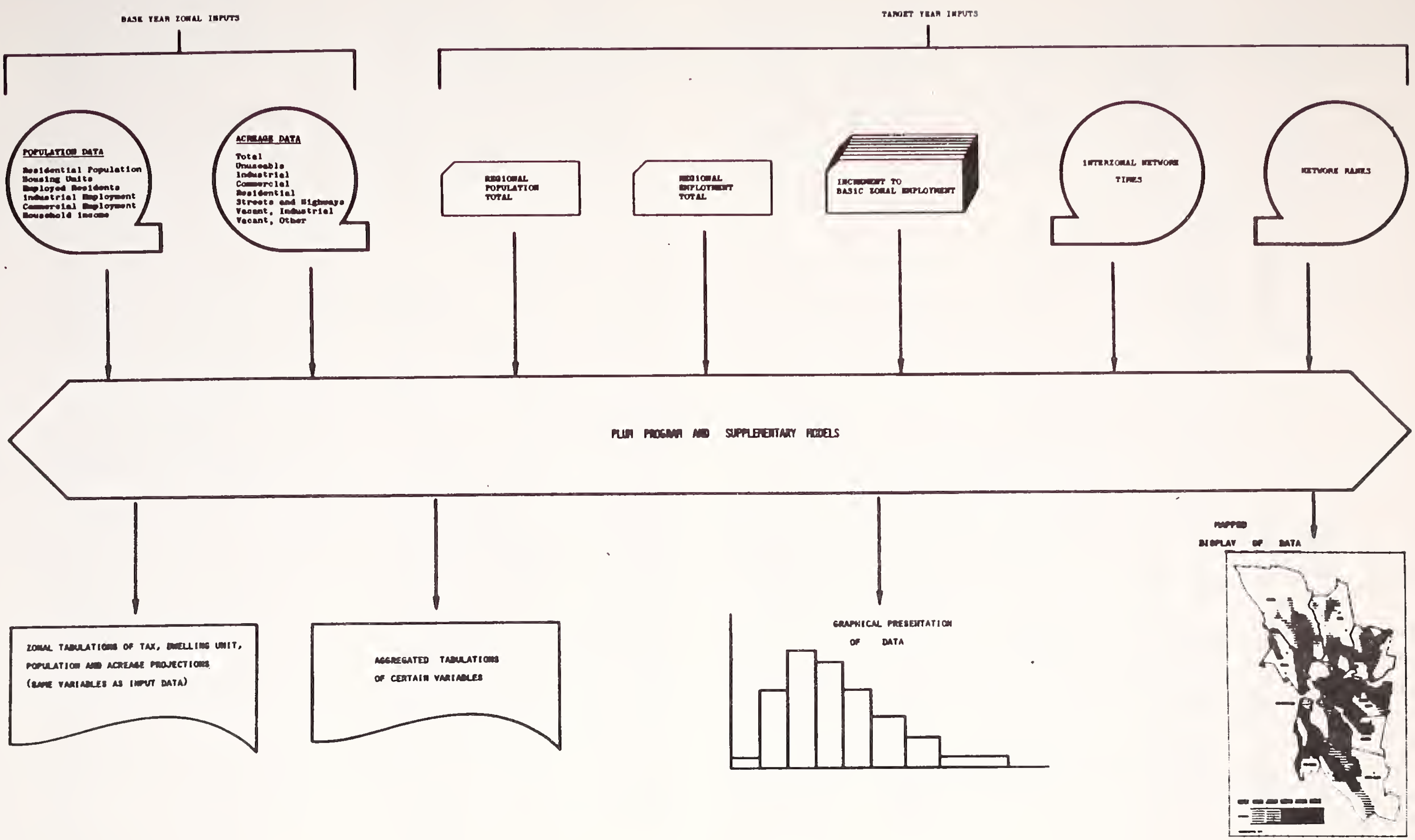


FIGURE 5.1-D4: "PLUM" INPUT REQUIREMENTS AND OUTPUT CAPABILITIES

(EXTRACTED FROM ROSENTHAL [1972], VOL. I, PAGE 40)

- Unusable land area
- Area devoted to streets and highways
- Land area devoted to "basic" employment
- Land area devoted to "population-serving" employment
- Area devoted to residential activity
- Area of vacant land zoned for industrial activity
- Total area of other vacant land.

These basic outputs may, if desired, be further broken down to provide estimates of the distribution of household income by zone, projected small-area tax revenues, dwelling units broken down by single and multi-family structures, employment broken down by industry code, etc. These latter outputs, it should be noted, however, are not standard outputs of the main model.

Resource Requirements for Model Application

Since much of the experience with the development and application of "PLUM" has centered around the model developed originally as part of the Bay Area Transportation Study it is a little difficult to make definitive statements concerning the resource and time requirements for model application elsewhere. Experience with the development and application of the model in San Diego suggests that a period of approximately 12 months is required for effective model development. This is, however, heavily contingent upon the status of data development in the area in question and the extent of the application which is envisioned. The "PLUM" research team at the University of California includes Dr. William Goldner as the Director, supported by a staff of 3-4 full-time professionals, 3 half-time graduate research assistants and 2 clerks/typists. This staff, it should be emphasized, is concerned primarily with research relating to the extension and further application of the model, rather than with its use as an on-line planning tool. Experience suggests, however, that an operational application would probably require the full-time activity of at least one and possibly more members of the research team for a period of up to 12 months. Additional

technical support would also be required in the course of data development.

Detailed documentation on the computer requirements associated with the calibration and application of the model are presented for both the IBM 360 and CDC 6000/7000 versions of the model in Rosenthal (1972). For a 291 zone data set, an IBM 360/40 with 256 K bytes of storage is required. Operating under DOS (FORTRAN), compilation and loading of the model for such a data set takes between 13-15 minutes and execution about 45 minutes. This total of approximately 1 hour of machine time may be reduced to between 40-45 minutes if an IBM 360/40 is used under the full operating system. If the area system is expanded to include approximately 600 zones it may be anticipated that the machine time requirements would be expanded by a factor of 3 or 4 times.

The bulk of the recent work which has been performed by the "PLUM" research time has utilized CDC rather than IBM equipment. Core requirements for running the model in the CDC environment are roughly 4000_8 plus 11110_8 locations for each 100 zones. For the same system of 291 zones cited before, the time requirements for a single run of the model are approximately 124 central processor seconds on a CDC 6400 machine and 10 CP seconds on a CDC 7600.

It should be emphasized that the above figures apply to individual model runs. They do not include any estimates of the time required for data assembly and analysis. Experience suggests that this is likely to be considerably in excess of the figures quoted above, independent of the machine used.

Examples of Model Application

By far the major applications of "PLUM" have been in the Bay Area of San Francisco.. The model was originally developed as part of the Bay Area Transportation Study, and was used to provide a basic set of projections for that study to the years 1980 and 1990. Since that time it has been used by the "PLUM" research team to evaluate the impact of alternative airport locations in the San Francisco Bay area, to evaluate alternative development control policies for the San Francisco Bay shoreline, and as a vehicle for detailed, small-area analysis in Marin

County. In addition, the model has recently been applied successfully at a regional scale in San Diego, California.

Each of these applications included a number of incremental improvements in the structure and output capabilities of the model. The model has, in a very real sense, evolved continuously over a period of several years, with the results of each evolution being incorporated directly within an operational application.

General Commentary

As noted earlier, "PLUM" is a direct descendent of the original "Lowry Model", developed by Dr. Ira S. Lowry in 1963. As such, it has benefitted considerably from much of the other work which has been done on Lowry-type formulations in other parts of the United States and overseas. It has also probably been subjected to a more intensive, sustained research activity than any other one of the models discussed in this chapter. The result is a compact, maleable formulation with a relatively strong theoretical base and an effective set of supporting software. The model has a proven ability to produce usable projections of total population, employment and growth land use acreages at a small-area level for use in support of regional transportation and related planning activities. Some of the more recent modifications which have been made to the model have expanded its utility considerably - this comment relates particularly to the provisions which have been made in later versions for disaggregation of the basic model outputs into their component characteristics and to the work which has been performed on projecting future tax revenues. The model lies in the public domain and is readily available to potential users.

Counterbalancing these assets are a number of problem areas. Perhaps the most significant of these relate to the basic structure of the model itself.

The requirement to make exogenous, small-area projections of "basic" employment prior to the operation of "PLUM" places a significant burden on the potential user. In the case of the original San Francisco work a separate model - entitled BEMOD - was developed for this purpose. A similar, separate modeling ability is required for any other application of the model. In a

directly related vein, one of the major problems facing the user is the development of a clear distinction between the "basic" and "population-serving" categories of employment. This is by no means as simple as it may appear on the surface, and may in fact represent a fairly significant task to be accomplished during the course of initial data assembly.

The model is essentially cross-sectional in format. That is, its calibration is based exclusively upon relationships developed for a single point in time. It does not incorporate within its structure any direct treatment of lagged variables or of the explicit dynamics of urban growth. This may be overcome, in part, by operating the model over a succession of relatively short recursion periods for forecasting purposes.

Finally, it should be noted that effective calibration of the model depends very heavily upon the estimation of the set of three spatial allocation functions described in the preceding sections. Much of the more recent development work has focused on the refinement of these functions. It may be argued that considerable additional work needs to be performed in this area, particularly with respect to effective representation of differences in mode-specific travel times and the further refinement of the set of "attractiveness" indices used in the current formulation of the model. A similar comment may also be made with respect to the current, somewhat simplistic, structure of the land use accounting procedures used to allocate increases in activity to specific land areas. In both cases, the argument may be made that the benefits which acrue from a simple, readily understandable conceptual structure may be seriously compromised by an overly simplistic empirical interpretation of that structure, leading potentially to serious specification errors and problems of forecast bias in the application of the model.

APPENDIX D-2

THE URBAN SYSTEMS MODEL

INTRODUCTION

The Urban Systems Model ("USM") has been developed by Alan M. Voorhees and Associates, Inc.Like "PLUM" it derives much of its basic structure from the original formulation of the "Lowry Model", though in the case of "USM" the development was based primarily upon work performed by A.G. Wilson and others in the United Kingdom.

The model has been applied successfully to the North Central Region of Texas. It is currently being used to test and evaluate a variety of alternative future regional planning policies for that region. The model is currently being incorporated as a load-module, with complementary user documentation, as part of the AMV TRIPS battery of computer programs.

A simple, concise description of the model is provided in Voorhees and Associates (1972). Discussions of some of the developmental work performed in the United Kingdom which underlies its structure is presented in Goldner (1971b), Wilson (1967), and Turner (1970).

MODEL STRUCTURE

"USM" is designed to operate as an integrated set of activity-allocation submodels which distribute projections of future region-wide activity to a set of smaller subregions or zones. The allocation is performed as a function of:

- Relative, inter-zonal transportation "costs", expressed in terms of either time or money;
- Measures of the intrinsic and relative "attractiveness" of individual zones for particular activities; and
- Measures of available "holding capacity" for each zone.

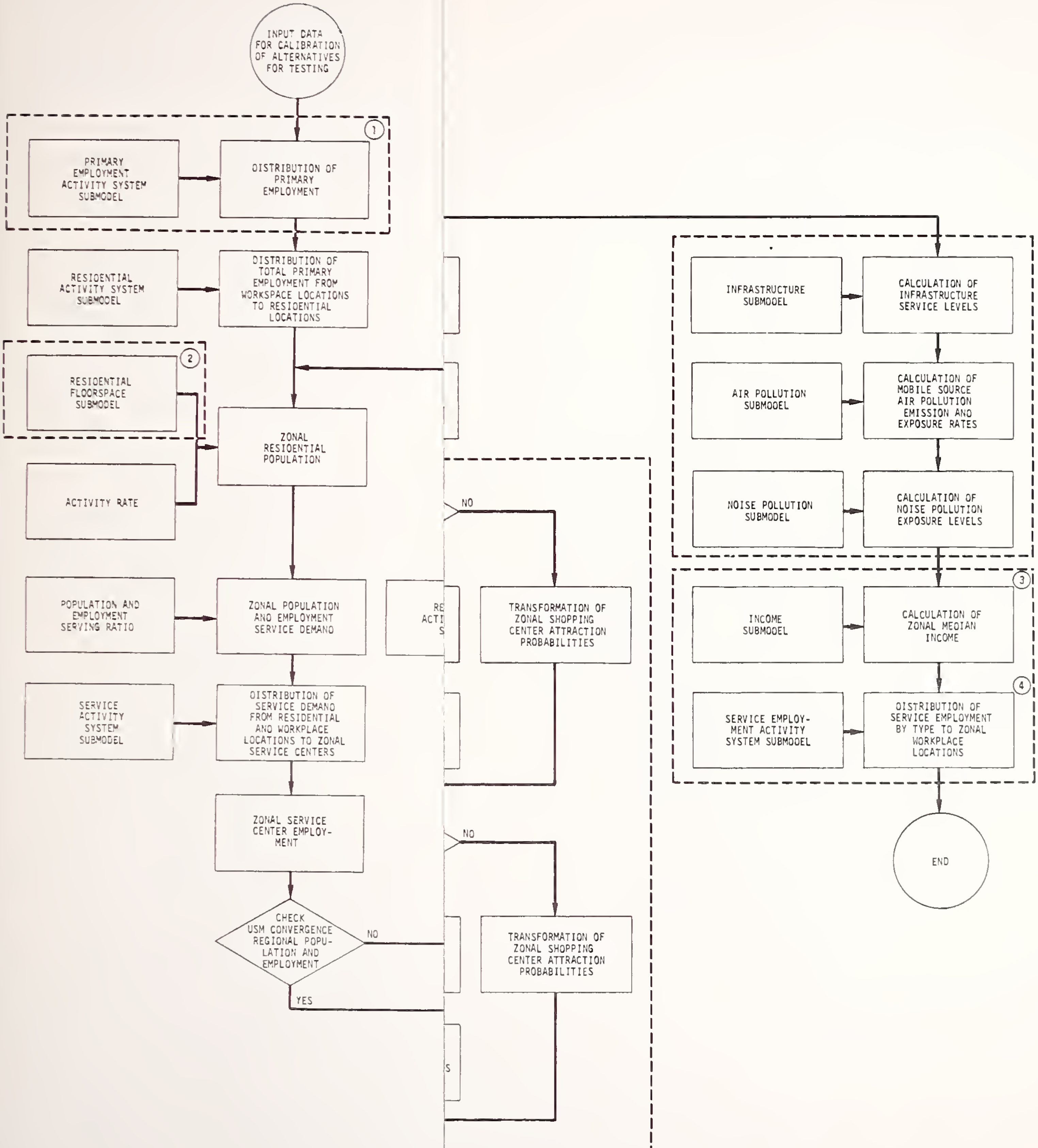
The basic structure of the model is very similar to that outlined previously for "PLUM". Total employment is divided into two categories, labeled in this case "primary" and "service". The categories correspond to those defined in the discussion of "PLUM" as "basic" and "population-serving". Given regional projections of total population, "primary", and "service" employ-

ment for a given forecast-year, together with an existing small-area distribution of "primary" employment, the model distributes employees from work-places to residential locations and estimates "service" demand (i.e., "service" employment) with respect to residence and work-place location. The sequence in which these operations are performed is conceptually the same as for "PLUM". The solution procedure is, however, somewhat different, being based upon a reformulation of the original "Lowry Model" by the Mathematical Advisory Unit of the Ministry of Transport, based on the concept of constrained entropy maximization.

As in the case of "PLUM" the model is designed to operate in an iterative manner for any given forecast interval. The structure of the operations is illustrated schematically in Figure 5.1-D5.

Given an initial estimate of the projected spatial distribution of "basic" employment the model first distributes the households associated with this employment. It then estimates the distribution of "service" employment with respect to these households and the original distribution of "basic" employment. Finally, the households associated with that "service" employment are distributed to residential locations and the model proceeds iteratively towards a convergence with the total regional projections of population and employment for the particular forecast interval. Once this regional convergence has been satisfied, the model then checks to ensure that small-area holding capacities and constraints have been met, and makes any necessary re-allocations. The model is again essentially set in a static equilibrium format. It is calibrated for a single point in time only. It differs from "PLUM", however, in that it incorporates land indicators of locational attractiveness for each activity and each zone. These are expressed as activity-specific measures for a point in time prior to that selected as the base-year for calibration. An example might be the use of net residential floor space as a measure of attractiveness for residential activity. The time lag is typically approximately 5 years.

The model is calibrated by estimating the parameter in a negative exponential travel "cost" expression for each of the three major activity combinations - i.e.,"home-to-work", "Home-to-shop" and "work-to-shop". The process is essentially analogous to estimating a parameter for each of the three spatial allocation functions employed in "PLUM". The method used to estimate



INPUT DATA FOR CALIBRATION OF ALTERNATIVES FOR TESTING
1
PRIMARY EMPLOYMENT ACTIVITY SYSTEM SUBMODEL
DISTRIBUTION OF PRIMARY EMPLOYMENT
RESIDENTIAL ACTIVITY SYSTEM SUBMODEL
DISTRIBUTION OF TOTAL PRIMARY EMPLOYMENT FROM WORKSPACE LOCATIONS TO RESIDENTIAL LOCATIONS
2
RESIDENTIAL FLOORSPACE SUBMODEL
ZONAL RESIDENTIAL POPULATION
ACTIVITY RATE
POPULATION AND EMPLOYMENT SERVING RATIO
ZONAL POPULATION AND EMPLOYMENT SERVICE DEMAND
SERVICE ACTIVITY SYSTEM SUBMODEL
DISTRIBUTION OF SERVICE DEMAND FROM RESIDENTIAL AND WORKPLACE LOCATIONS TO ZONAL SERVICE CENTERS
ZONAL SERVICE CENTER EMPLOYMENT
CHECK USM CONVERGENCE REGIONAL POPULATION AND EMPLOYMENT
NO
YES
NO
TRANSFORMATION OF ZONAL SHOPPING CENTER ATTRACTION PROBABILITIES
NO
TRANSFORMATION OF ZONAL SHOPPING CENTER ATTRACTION PROBABILITIES
INFRASTRUCTURE SUBMODEL
CALCULATION OF INFRASTRUCTURE SERVICE LEVELS
AIR POLLUTION SUBMODEL
CALCULATION OF MOBILE SOURCE AIR POLLUTION EMISSION AND EXPOSURE RATES
NOISE POLLUTION SUBMODEL
CALCULATION OF NOISE POLLUTION EXPOSURE LEVELS
3
INCOME SUBMODEL
CALCULATION OF ZONAL MEDIAN INCOME
4
SERVICE EMPLOYMENT ACTIVITY SYSTEM SUBMODEL
DISTRIBUTION OF SERVICE EMPLOYMENT BY TYPE TO ZONAL WORKPLACE LOCATIONS
END

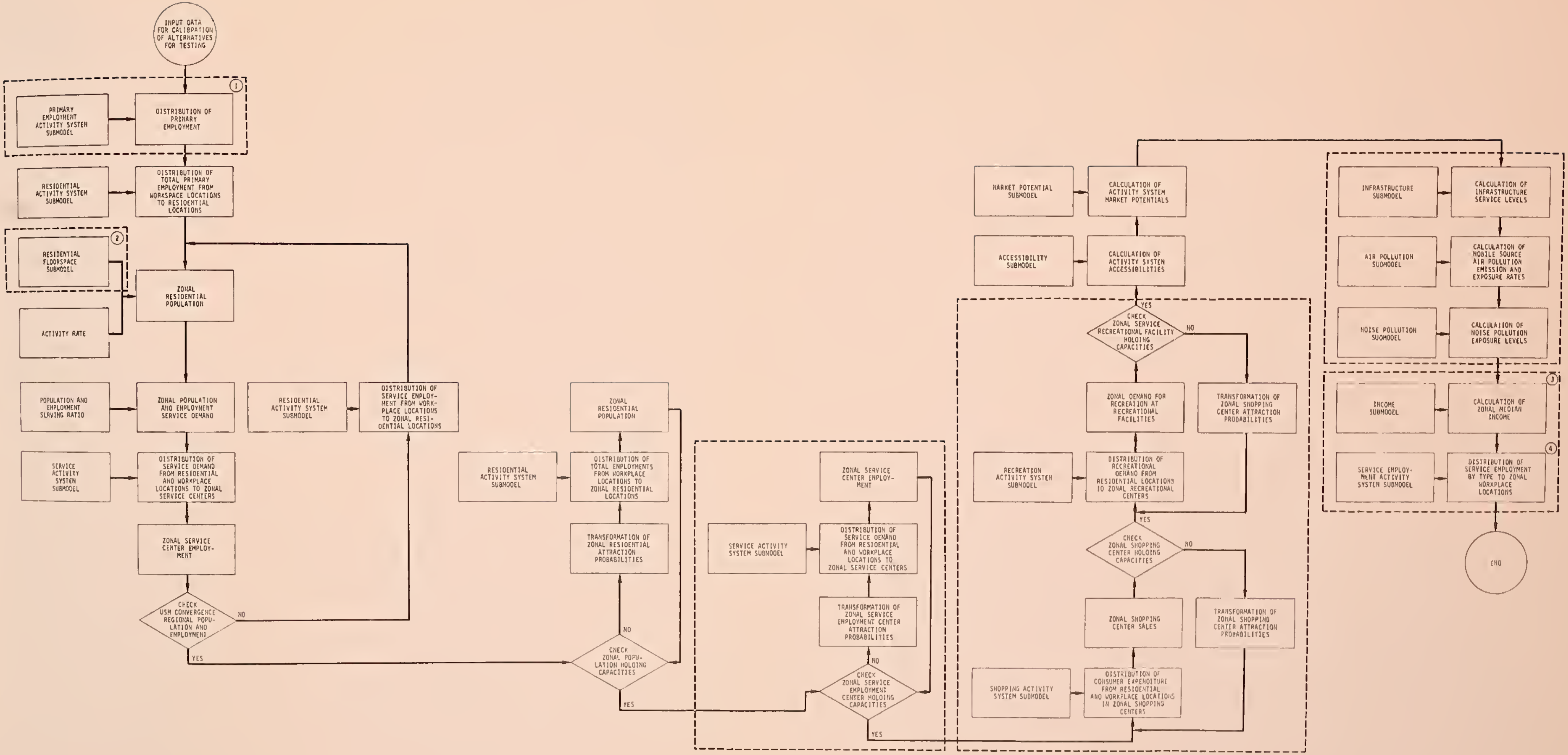


FIGURE 5.1 05: URBAN SYSTEMS MODEL OPERATIONAL PROCEDURE (EXTRACTED FROM VOORREES AND ASSOCIATES (1972))

the value of these parameters is based on an efficient process of interpolation developed by the Ministry of Transport involving the comparison of observed and estimated trip-length frequency distributions.

For forecasting purposes, the model is employed recursively, with the recursion period being approximately 5 years.

The standard outputs of the model include, in addition to small-area estimates of population and "service" employment estimates of small-area consumer accessibilities to activity locations and small-area indices of market-potentials with respect to consumer locations. These measures are computed immediately after a final, constrained set of population and employment estimates have been generated for each forecast year.

Additional, optional outputs which may be generated by means of a series of supplementary submodels employing as input the outputs of the main model, supplemented by exogenous variables as necessary, include:

- Estimates of available consumer expenditures from residences and work-places to shopping-center locations;

- Demand for recreation from residences to recreational locations;

- Level of sewer service per resident and per "primary" employee;

- Level of water service per resident and per "primary" employee;

- Estimates of air pollution emission rates for mobile sources (i.e., highway and transit system emissions);

- Estimates of air pollution exposure rates from mobile sources (i.e., from highway and transit sources);

- Estimates of noise pollution exposure rates from large stationary sources (e.g., airports);

- Estimates of "primary" employment by aggregated industry code;

- Estimates of "service" employment by aggregated industry code;

- Estimates of lagged net residential floor space, required as an attractiveness index if the model is to be used in a recursive forecasting mode; and

- Estimates of median income.

All of the above outputs are summarized on a small-area basis for each forecast year. The submodels are based in most instances upon multiple linear regression relationships.

APPLICATION

The model may be applied in any one of four different ways:

- As a straightforward forecasting tool to predict the future small-area distribution of population and employment within a region;

- As a constrained forecasting tool to predict future amounts of activity by small-area as classified counts of population, employment and land use.

- As a constrained forecasting device to predict the future small-area distribution of activity with the development of certain small-areas within the region limited by planning, institutional, physical or environmental constraints; and

- As an evaluation tool in which alternative regional planning policies or programs are evaluated in terms of their probable impact on the future distribution of urban activity.

Policy inputs and projected system alternatives are expressed within the forecasting process in terms of:

- Inter-zonal travel time or cost matrices, based upon conventional highway and transit networks prepared for the appropriate forecast-year for the appropriate policy or alternative;

- Identification of zoning and open-space controls, in terms of small-area constraints on the future use of land;
- Expressions of land development potential;
- Identification of projected levels of public utilities (i.e., water and sewer service) service levels;
- Identification of regional development policies; and
- Identification of environmental pollution (i.e., air and noise pollution) constraints.

The model is programmed in FORTRAN IV and is currently operational on IBM OS/360 hardware. The program is modular in format and the set of supplementary submodels which are designed to build on the outputs of the main model utilize a standard multiple linear regression program which may be operated independently of the main algorithm. The program package is currently proprietary to Alan M. Voorhees and Associates, Inc.

Data Input Requirements and Output Capabilities

The model may be calibrated at a variety of different levels of sophistication, depending on the number of supplementary outputs which are required. As a minimum (see 5.1-D6[1]) estimates of small-area population, "primary" and "service" employment, "service" employment and population holding capacities, total area, highway/transit interzonal travel times, and work-home and home/work-service trip length frequency distributions are required for a given base-year.[2]

1) Fig 5.1-D6 is a reproduction of Fig 5.1-D5 in Voorhees and Associates (1972).

2) The term "base-year" as used here applies to the year selected for model calibration. It is used in this manner throughout the present section. It corresponds to the term "calibration-year" employed in Fig 5.1-D5 ; the term "base-year" used in that figure refers to the lagged time period prior to the year selected for calibration used in the construction of lagged variables.

Sector	Minimum Data Requirements	Optional Data Requirements
Transportation	Calibration year: • peak composite highway-transit skim tree • work-home trip length frequency distribution, mean trip length • home, work-service trip length frequency distribution, mean trip length	Calibration year: • off-peak composite highway-transit skim tree • home, work-shop trip length frequency distribution, mean trip length • home-recreation trip lenght frequency distribution, mean trip lenght • highway vehicle miles of travel on freeways, arterials and collectors by zone or district • transit vehicle miles of travel by conventional bus, rapid bus and rapid rail by zone or district
Land Use	• zonal area	Base year zonal: • net residential land area • net primary and service employment land area by type of employment • net vacant land area • net recreational land area • no. dwelling units
Activity	Base year zonal: • primary employment • service employment • total employment • population Calibration year zonal: • primary employment • service employment • total employment • population • service employment holding capacity • population holding capacity	Base year zonal: • primary employment by type • primary employment accessibility • service employment by type • service employment accessibility • shopping center sales • recreational usage • median income Calibration year zonal: • primary employment by type • service employment by type • shopping center sales • available consumer expenditure • recreational usage • recreational demand • median income
Infrastructure		Calibration year zonal: • sewer capacity • water capacity
Pollution		Calibration year zonal: • noise emission levels

FIGURE 5.1-D6: DATA REQUIREMENTS - CALIBRATION

(EXTRACTED FROM VOORHEES AND ASSOCIATES [1972])

In addition, information is also required for a point in time approximately 5 years prior to the base-year used for calibration on small-area population, "primary" employment and "service" employment.

If a more sophisticated version of the model is to be developed, these data requirements should be expanded as illustrated in Fig 5.1-D6 to include a more extensive set of activity, land use and transportation data inputs, together with additional inputs on utility capacity and noise emission levels.

The data requirements for forecasting are summarized in Fig 5.1-D7 Again, distinction is drawn between the requirements associated with the simplest possible form of the model and those which are necessary for more sophisticated applications. At a minimum level data is required over and above that utilized in calibration on future regional population, "primary" employment and "service" employment totals. Equivalent, small-area data is required on the future location of "primary" employment, future "service" employment and population holding capacities and future inter-zonal highway/transit travel times. For more sophisticated applications these requirements are expanded again to include additional activity, land use and transportation data, together with projected forecast-year information on utilities capacity and noise emission levels. Each of the items cited above is required for each year for which a forecast of the future distribution of activity is to be generated.

The basic set of outputs which may be generated by "USM" for each forecast-year and each small-area within the study region include small-area projections of population, "service" and total employment, activity densities, trip length frequency distributions, and estimates of regional accessibilities and market potential measures. Optional outputs which may be derived by supplementary submodels include parallel estimates of shopping center sales, recreational usage, additional trip lengths, accessibility and market potential measures, estimated air pollution and noise pollution rates, income, net residential floor space and disaggregated "primary" and "service" employment estimates.

Sector	Minimum Data Requirements	Optional Data Requirements
Transportation	Forecasting years: • peak composite highway-transit skim tree	Forecasting Years: • off-peak composite highway-transit skim tree • highway vehicle miles of travel on freeways, arterials and collectors by zone or district • transit vehicle miles by travel by conventional bus, rapid bus and rapid rail by zone or district
Land Use	• zonal area	Base years zonal: • net primary and service employment land area by type of employment • net vacant land area • net recreational land area • no. dwelling units
Activity	Base years zonal: • primary employment Forecasting years regional: • primary employment • service employment • population Forecasting years zonal: • primary employment • service employment holding capacity • population holding capacity	Base years zonal: • primary employment accessibility • service employment accessibility Forecast years zonal: • available consumer expenditure • recreational demand
Infrastructure		Forecast years zonal: • sewer capacity • water capacity
Pollution		Forecast years zonal: • noise emission levels

FIGURE 5.1-D7: DATA REQUIREMENTS - FORECASTING

(EXTRACTED FROM VOORHEES AND ASSOCIATES [1972])

Resource Requirements and Model Application

The model is programmed in FORTRAN and is operational on IBM OS 360/50 or larger hardware with approximately 250 K bytes of storage. No documentation is available on the estimated machine time and manpower requirements associated with the operational application of "USM". It may be expected, however, that they are similar to those associated with "PLUM".

Examples of Model Application

To date, the only example of an operational application of the "USM" in the United States is that which is recently being completed for the North Central Region of Texas. The results of this study give every indication of a successful calibration and application of the model.

The prototype version of the model was initially developed and successfully applied in Southwest England. Similar versions of the model have also been employed successfully in other areas of the United Kingdom (see, for example, the studies reported in Goldner (1971[b])).

GENERAL COMMENTARY

Many of the general comments made with respect to "PLUM" apply also to "USM". The model is basically very similar in structure. It does, however, provide (particularly through the set of optional submodels) for a somewhat broader set of outputs than does "PLUM". Its calibration process is also much more compact and much more clearly defined. The model also has the advantage of being supported by a major consulting organization and of incorporation within a frequently used transportation planning package. The package is, however, proprietary in nature.

The major shortcomings associated with the model are essentially the same as those cited earlier in the discussion of "PLUM". It is necessary to provide exogenous projections of small-area "primary" employment for each individual forecast year. The calibration process also again places considerable reliance upon cross-sectional travel data, though this is supplemented to a degree by a set of lagged " attractiveness" indices.

APPENDIX D-3

THE EMPIRIC ACTIVITY ALLOCATION MODEL

INTRODUCTION

The "EMPIRIC" model differs from the two discussed previously in at least three important respects. It is formulated directly as a "dynamic" rather than as a "static" model, it deals explicitly with the simultaneous nature of development, and it has a considerably less rigid and empirically oriented structure than the previous two. It consists essentially of a set of simultaneous linear-difference equations designed to project future small-area changes in population and employment, supported by a relatively complex land-accounting process. The coefficients in the main equations are estimated by simultaneous regression techniques.

The model (or, more appropriately, the modeling technique) was developed originally for the Eastern Massachusetts Regional Planning Program in Boston. It has subsequently been applied successfully in Southeastern Massachusetts, Washington, D.C., Minneapolis-St. Paul, Denver, Winnipeg, and Toronto. It is currently being applied in Seattle and Atlanta. More detailed descriptions of the model than that presented here are given in Peat, Marwick, Mitchell & Co. (1972[a], 1972[b], 1972[c], 1973) and Carter (1971).

General Description

The model is designed to perform three major functions, essentially similar to those identified previously for "PLUM" and "USM". They are:

- To allocate regional projections of future population, employment and land use, broken down by category, between a set of smaller subregions or zones;

- To assess the probable impact of alternative regional planning policies on the future distribution of regional growth; and

- To provide a foundation for the evaluation and coordination of future policy decisions in a variety of different functional areas.

"Activities" are defined within the model as classified, small-area counts of households and employment (broken down, for example, by income, size or industry type), coupled with

parallel estimates of land use acreages classified by type. Planning policies are expressed in terms of regional accessibility and opportunity measures derived from conventional highway and transit network analyses; water- and sewer-system service-areas; zoning, open-space and environmental/land conservation controls; the projected location of major development, and region-wide housing and employment location policies. The model is calibrated using small-area activity and policy data assembled for two separate points in time, usually approximately 10 years apart. It is then applied recursively to generate forecasts of the future distribution of activity for points 10, 20, 30, etc. years into the future, conditional upon the pursuit of specific regional planning policies.

MODEL STRUCTURE

The model consists of four major components (see Fig 5.1-D8). These are:

- Module #1 - Simultaneous Equation Module
- Module #2 - Land Consumption Module
- Module #3 - Supplementary Sub-Models
- Models #4 - Forecast Monitoring Module

The first and central module consists of a set of simultaneous, linear-difference equations relating overserved changes in the subregional distribution of population and employment characteristics over the calibration interval one to the other, to their original base-year distribution, and to the effects of specific planning policies implemented over the calibration period. The module is calibrated using conventional, simultaneous regression techniques.[1] Its outputs are expressed usually in terms of the estimated number of households and employees within each small-area, broken down, respectively, by income class and industry type. All

1) The specific technique employed is two-stage simultaneous least-squares regression.

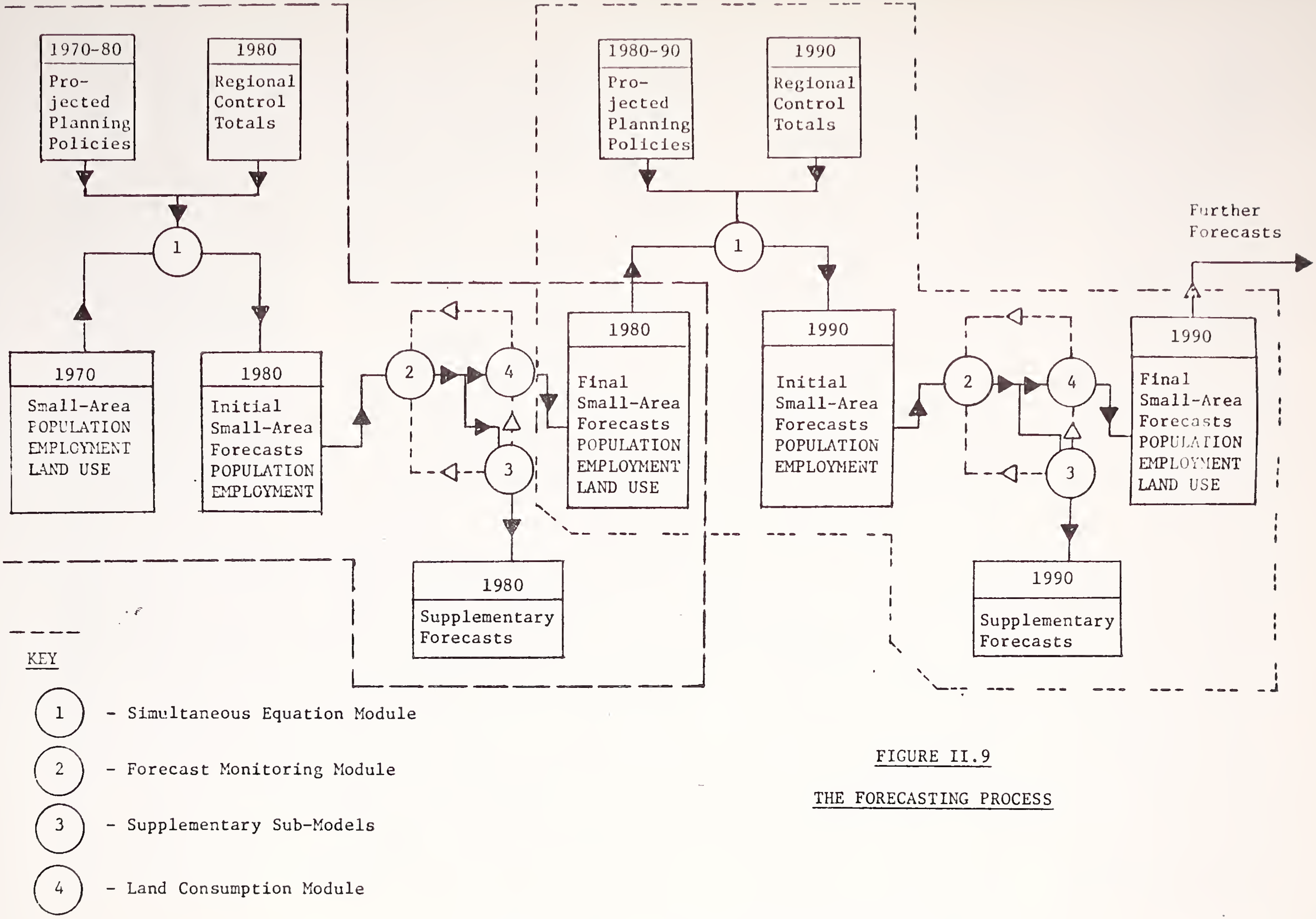


FIGURE II.9

THE FORECASTING PROCESS

FIGURE 5.1-D8: STRUCTURE OF "EMPIRIC" MODEL

(EXTRACTED FROM PEAT, MARWICK, MITCHELL & CO. [1972a], PAGE 35)

variables are typically expressed as "shares" of a regional total, with the dependent variables in each equation being expressed as subregional "changes in shares" of activity over the calibration interval. This is illustrated conceptually in Fig. 5.1-D9 Figure 5.1-D10 presents a simple, numerical illustration of a calibrated, simultaneous-equation module.

These initial estimates of subregional population and employment are translated into equivalent changes in classified small-area land use by means of the second,"land-consumption", module. This is again calibrated using data assembled for the same two points in time. It accepts as input the outputs of the simultaneous equation module, together with information on the base-year distribution of land use within each small area and the range of permissible development densities for each activity. Its output is a detailed updated accounting of land-use, broken down by type, within each small area for each forecast year.

The third component consists of a set of supplementary submodels, which are operated in parallel with the land consumption model and are designed to further disaggregate the initial population, employment and land-use projections into a more detailed set of component characteristics. Typical submodel outputs include estimates of small-area population broken down by age or race, estimates of numbers of households by size, housing units by type, etc. These submodels are again calibrated using data assembled for two points in time, and usually take the form of either ordinary or simultaneous regression relationships or simple equivalence matrices. They may be integrated directly within the main model, they may be operated as a totally separate exercise or they may be excluded entirely.

For purposes of model application, the three calibrated modules outlined above are linked together with a fourth, "forecast-monitoring" module to from a single forecasting chain, designed to yield recursive estimates of the future subregional distribution of activity and land use for points 10, 20, 30, etc. years into the future. Each forecast is conditional upon an externally specified "regional total" of population and employment for the region as a whole, and also

$$\left[\begin{array}{l}\text{CHANGE in}\\ \text{sub-regional}\\ \text{ACTIVITY "i"}\\ \text{over}\\ \text{TIME "}\Delta t\text{"}\end{array}\right] = F\left[\begin{array}{l}\text{SIMULTANEOUS}\\ \text{CHANGE in}\\ \text{OTHER sub-}\\ \text{regional}\\ \text{ACTIVITIES "j"}\\ \text{over}\\ \text{TIME "}\Delta t\text{"}\end{array} + \begin{array}{l}\text{BASE-YEAR}\\ \text{CHARACTERISTICS}\\ \text{of}\\ \text{sub-regional}\\ \text{ACTIVITY at}\\ \text{TIME "}t_o\text{"}\end{array} + \begin{array}{l}\text{Sub-regional}\\ \text{PLANNING}\\ \text{POLICIES}\\ \text{effective}\\ \text{over}\\ \text{TIME "}\Delta t\text{"}\end{array}\right]$$

FIGURE 5.1-D9: STRUCTURE OF SIMULTANEOUS EQUATION MODULE IN "EMPIRIC" MODEL

(EXTRACTED FROM PEAT, MARWICK, MITCHELL & CO. [1972a], PAGE 7)

$$R_{1,k}(\Delta t) = +\ 0.3234\ R_{2,k}(\Delta t) - 0.0064\ R_{1,k}(t_o) + 1.9258\ Z_{1,k}(\Delta t)$$

$$R_{2,k}(\Delta t) = +\ 0.4166\ R_{1,k}(\Delta t) - 0.0061\ R_{2,k}(t_o) + 0.9640\ Z_{i,k}(\Delta t)$$

$$R_{3,k}(\Delta t) = +\ 0.1562\ R_{1,k}(\Delta t) - 0.0130\ R_{3,k}(t_o) + 0.9993\ Z_{2,k}(\Delta t)$$

where:

$R_{1,k}(\Delta t)$ = CHANGE IN POPULATION in district "k" over time period "Δt"

$R_{2,k}(\Delta t)$ = CHANGE IN WHITE COLLAR EMPLOYMENT in district "k" over time period "Δt"

$R_{3,k}(\Delta t)$ = CHANGE IN BLUE COLLAR EMPLOYMENT in district "k" over time period "Δt"

$R_{1,k}(t_o)$ = BASE-YEAR POPULATION in district "k" at time "t_o"

$R_{2,k}(t_o)$ = BASE-YEAR WHITE COLLAR EMPLOYMENT in district "k" at time "t_o"

$R_{3,k}(t_o)$ = BASE-YEAR BLUE COLLAR EMPLOYMENT in district "k" at time "t_o"

$Z_{1,k}(\Delta t)$ = CHANGE IN ACCESSIBILITY to EMPLOYMENT for residents of district "k" over time period "Δt"

$Z_{2,k}(\Delta t)$ = CHANGE IN ACCESSIBILITY to POPULATION for employers in district "k" over time period "Δt"

FIGURE 5.1-D10: A SIMPLE EXAMPLE OF A CALIBRATED SIMULTANEOUS EQUATION MODULE

(EXTRACTED FROM PEAT, MARWICK, MITCHELL & CO. [1972a], PAGE 19)

upon the presumed pursuit of a specific set of planning policies over the forecast interval. Such policies are expressed operationally in two ways.

For those policy measures which are incorporated as direct variables within one or other of the calibrated modules, the analyst must specify the future value of the appropriate policy variable for each subregion, each forecast year and each policy alternative. In the case of transportation inputs, for example, this implies the development of separate highway and transit networks for the years at each end of the calibration interval, together with equivalent networks for each forecast year and each policy alternative.[1)]

This process, clearly, is necessarily limited to those policies which exerted a significant influence on the pattern of growth over the calibration period. Other policy considerations must be treated somewhat differently, as indirect constraints to be imposed on the forecasting process. These are implemented in part through the land-consumption module and in part via the "forecast-monitoring" module built into the overall forecast chain.

They may be invoked in a variety of different ways to reflect, for example, pre-specified minimum or maximum activity levels in any subregion for any forecast year, variations in permissible density or subregional holding capacities, the restriction of particular areas of land to specific types or densities of development, the withholding of such areas from other forms of development, or the specification

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1) The actual inputs used by the model are not the networks themselves but rather the set of subregional travel-time matrices derived from minimum time path or similar analyses applied to each network. Alternatively, a set of simplified measures of transportation service may be employed which do not necessitate network-oriented analyses. This point is discussed in more detail in Lathrop (1965).

of proportional mixes of activity growth within a given subregion, etc.[1)]

Fig 51-D8 illustrates a simple forecast chain, indicating the relationship of the several components of the model one to the other. The chain is initiated by solving the initial set of simultaneous equations for each small-area in turn. The resultant projections of population and employment are then input to the forecast monitoring routine to determine whether any prespecified small-area activity constraints have been violated. If they have the initial projections are modified accordingly and the surplus/deficit of activity is reallocated. The monitored output is then fed into the land-consumption and submodel routines. Additional checks are then performed to identify contravention of prespecified density or land-availability requirements and to assure internal consistency of the forecasts. Appropriate admustments are made, if necessary, either internally within each module or via a feedback loop to the forecast monitoring routine. Finally, the full set of model outputs are displayed in both tabular and map form and an input data file created for the next forecast.

Figs 51-D11 & D12 summarize, respectively, the use of the model to generate a simple set of forecasts based on one single set of policy inputs for a succession of three forecast periods, and the schematic application of the model to test three alterative "policy scenarios", incorporating varying mixes of policy inputs, over a similar set of three forecast intervals.

APPLICATION

The model may be employed at varying levels of geographic and functional detail. The study area, for example, may range in size from a single county to a multi-county region or an entire state. The number of subregions within this area may vary from approximately 40 to 900. Similarly, the calibration interval may vary from as short as 5 years to as long as 12

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1) No attempt will be made here to discuss further the full set of constraints which may be invoked upon the forecasting process, nor to discuss in detail the procedures used for treating "direct" or "indirect" policy inputs. All these points are discussed in some considerable detail in Lathrop (1965).

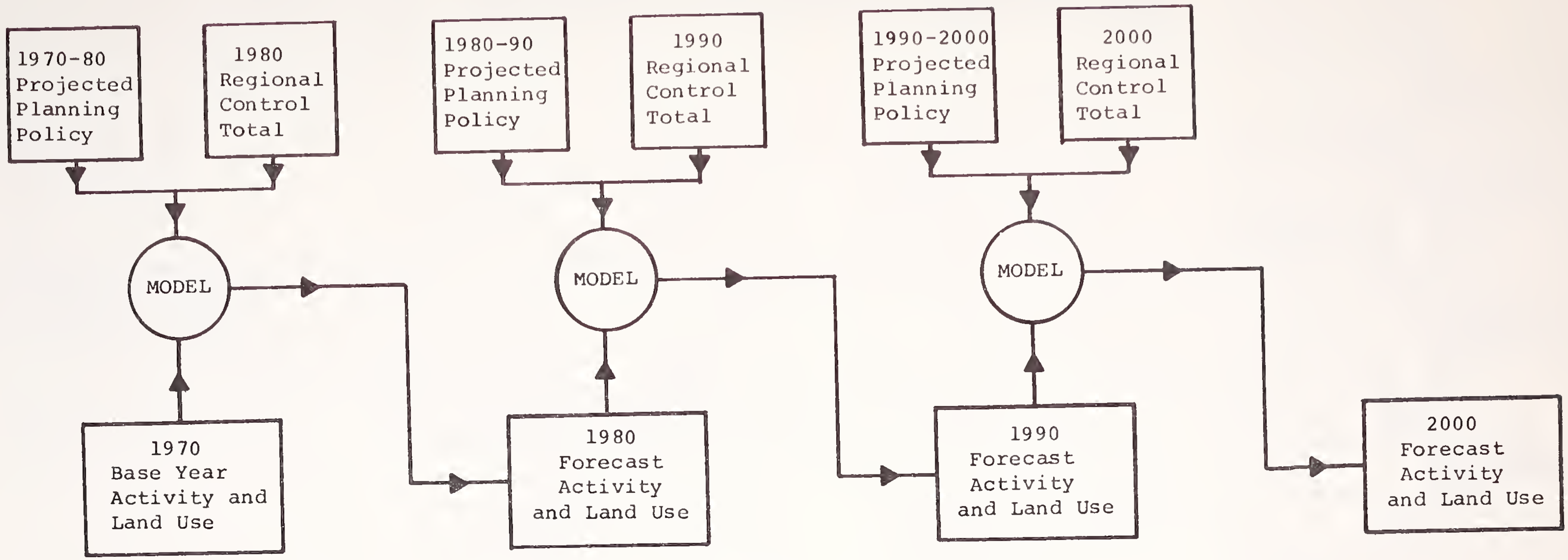

FIGURE 5.1-D11: EXAMPLE OF A SINGLE FORECAST CHAIN FOR PERIOD 1970-2000

(EXTRACTED FROM PEAT, MARWICK, MITCHELL & CO. [1972b], p. 11)

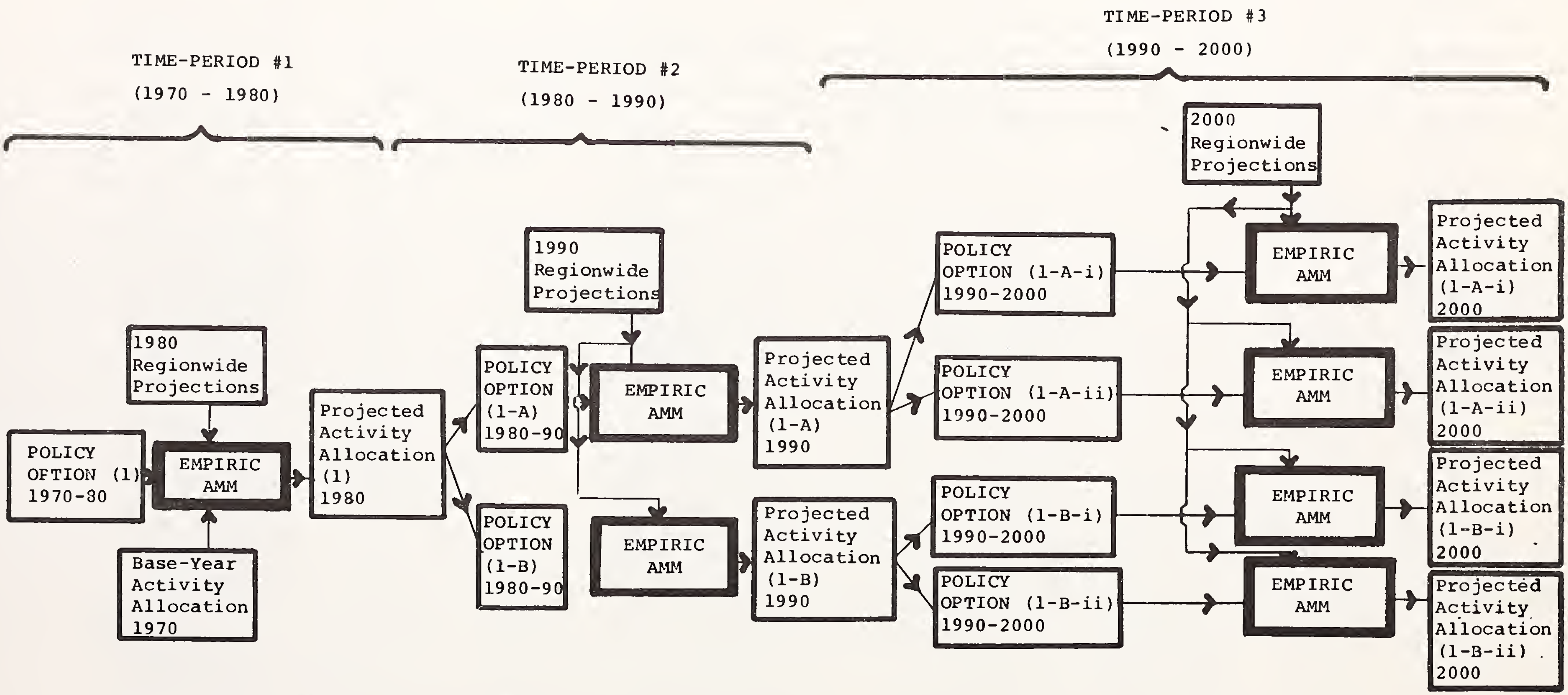

FIGURE 5.1-D12: SEQUENCING OF MULTIPLE POLICY SCENARIO EVALUATION OVER A SUCCESSION OF THREE TIME PERIODS

(EXTRACTED FROM PEAT, MARWICK, MITCHELL & CO. [1972b], page 257)

years. The number of equations in the simultaneous equation module may vary from a minimum of two (i.e., a model with only two endogenous variables - e.g., total population and total employment), up to more complex 12 or 15 equation structures, while the structure of the submodels, the land-consumption module and the forecast module may be similarly tailored to the particular requirements of the user.

The entire model is programmed in FORTRAN IV and is operational on both IBM OS/360 and IBM OS/370 equipment. The full model system consists of seventeen separate programs. These include basic data assembly and analysis routines; single-equation and simultaneous regression programs; correlation and factor analysis routines; forecasting and forecast-monitoring routines; the land-consumption module, and a set of standard report generation and computer mapping programs. All of the programs feature dynamic core allocation and are thus virtually unlimited with respect to capacity and the size of the data sets which they may handle.

The model system is supported by comprehensive user documentation and program manuals. It lies in the public domain and is currently being incorporated as an element within the U.S. Department of Transportation, Federal Highway Administration's IBM OS/360/370 battery of urban transportation planning programs.

Data Input Requirements and Output Capabilities

The model requires the assembly of a comprehensive, small-area data set for two points in time to serve as a foundation for calibration. In addition, specific policy inputs must be prepared, again at the small-area level, for each forecast-year and each policy alternative to be tested, together with appropriate regional forecasts of the activities to be allocated by the model. The full set of data inputs required for model calibration and the one single chain of forecasts are summarized schematically in Fig 5.1-D13. A typical set of calibration data inputs are described in more detail in Fig 5.1-D14

As noted earlier, the set of outputs generated by the model may be specified with a considerable degree of flexibility at the option of the user. They may vary from simple estimates of total population, employment and used land to extremely

	CALIBRATION INPUTS		FORECASTING INPUTS FOR ONE POLICY SCENARIO			
	YEAR		YEAR			
	1960	1970	1970	1980	1990	2000
<u>INTERNAL ACTIVITY DATA</u>						
. Demographic	●	●	●			
. Employment	●	●	●			
. Land Use	●	●	●			
<u>EXTERNAL ACTIVITY DATA</u>						
. Demographic	●		●	●	●	
. Employment	●		●	●	●	
<u>POLICY DATA</u>						
. "Direct" Policy Variables (e.g., Transportation, Utilities, Developable Land, Nominal Development Densities, etc.)	●	●	●	●	●	●
. "Indirect" Policy Variables (e.g., Development Controls, Density Overrides, Conservation and Open-Space, Land Suitability, Major Developments, Fair-Share Housing, etc.)			●	●	●	●
<u>REGIONAL ACTIVITY FORECASTS</u>						
. Demographic				●	●	●
. Employment				●	●	●

FIGURE 5.1-D13: TYPICAL SET OF DATA INPUTS FOR "EMPIRIC" ACTIVITY ALLOCATION MODEL

(EXTRACTED FROM PEAT, MARWICK, MITCHELL & CO. [1972[a]], p. 47)

A) INTERNAL ACTIVITY DATA

1) DEMOGRAPHIC INPUTS
(All data required at District Level for 1960 and 1970)

. No. Families in Households x Income Category (3-6 classes)
. No. Unrelated Individual Households
. No. Households x Size (4-8 classes)
. No. Households x No. of Workers (2-4 classes)
. No. Households x Race (2-3 classes)
. No. Households x Auto Availability (2-4 classes)
. Population in Households x Age (6-8 classes)
. Population in Group Quarters
. No. Households x Housing Unit Type (2-4 classes)

2) EMPLOYMENT INPUTS
(All Data required at District Level for 1960 and 1970)

. No. Employees at Place of Work x Industry (4-8 classes)
. No. Employees at Place of Work x Land Use (4-8 classes)

3) LAND-USE INPUTS
(All Data required at District Level for 1960 and 1970)

. Land-Use Acreages x Use (4-8 classes)
. Area of Developable Vacant Land
. Area of Undevelopable Land
. Total Area

B) EXTERNAL ACTIVITY DATA
(All Data required for each external district for 1960, 1970, 1980, and 1990)

. Total Households
. Total Employment

C) POLICY DATA

1) 'DIRECT' POLICY INPUTS
(Transportation Data required for all Internal and External Districts; All Other Data required for Internal Districts only. All data required for years 1960, 1970, 1980, 1990 and 2000)

. Transportation, a) Highway - District-Level Travel Time Matrices x Trip Length Distribution
b) Transit - District-Level Travel Time Matrices x Trip Length Distribution
. Water Service - Area Served
. Sewer Service - Area Served

2) 'INDIRECT' POLICY INPUTS
(Data required for Appropriate Activity/District Combinations only for selected years 1970, 1980, 1990, 2000)

. Modifications to Nominal Development Densities
. Developable Land Withholdings
. Release of Land Previously Unsuitable for Development
. Size of Major Developments, Renewal and Redevelopment Projects
. Activity-Balance Requirements
. 'Fair-Share' Housing Requirements
. Minimum and/or Maximum Activity Levels

D) REGIONAL ACTIVITY FORECASTS
(Data required for Internal Study-Area only for 1980, 1990, and 2000)

. Regional Total Families in Households
. Regional Total Unrelated Individual Households
. Regional Total Employment x Industry (4-8 classes)
. Regional Total Group Quarters Population
. Regional Total Population x Age (6-8 classes)

FIGURE 5.1-D14: ILLUSTRATIVE DATA INPUTS FOR CALIBRATION AND FORECASTING

(EXTRACTED FROM PEAT, MARWICK, MITCHELL & CO. [1972[a]], PAGE 50)

(n.b.: Policy Inputs based on one Policy Scenario for the Years 1970-80, 1980-90, 1990-2000)

detailed breakdowns of these activities together with supplementary estimates of service requirements, tax revenues or development densities. A typical set of outputs is illustrated in Fig. 5.1-D15. Each of these data items is generated for each small-area within the region, for each forecast-year and for each policy alternative.

In addition to these standard outputs, the model also produces stratified estimates of regional accessibilities to both residential and employment activities as part of the computational process. These may be tabulated and displayed graphically at the option of the user.

Resource Requirements for Model Application

Experience with the development and application of the model in a number of different metropolitan areas has indicated that a minimum of between 9 and 12 months is required for successful development and application of the model. By far the largest proportion of this time is required for data assembly activities. These typically consume at least 6 months and require the allocation of between 6-12 man-months of professional time together with up to 1 1/2 - 2 times that amount of technical support. Model calibration, depending upon the detailed structure of the models to be calibrated, typically consumes approximately three months and involves some 4-6 man-months of professional time. Creation of a single set of forecasts for three separate forecast-years requires between 1 1/2 - 2 months for each "policy scenario" to be tested including 2-3 man-months of professional time and approximately the same amount of technical support. Computer requirements generally range between 15-25 hours of IBM OS/360 Model 65 time or its equivalent.

It should be emphasized that the resource requirements outlined above are approximate and are based upon broad generalities. They may vary considerably depending upon the specifics of a particular application.

Examples of Model Application

"EMPIRIC" has probably been more widely utilized than any other single land-use model. It has been successfully calibrated and applied in seven different metropolitan areas, and is

- TOTAL NO. OF HOUSEHOLDS
- NO. OF FAMILIES IN HOUSEHOLDS x INCOME
  (3-5 classes)
- NO. OF UNRELATED INDIVIDUAL HOUSEHOLDS (URI)
  (1 class)
- GROUP QUARTERS POPULATION
  (1 class)
- NO. OF HOUSEHOLDS x SIZE
  (3-8 classes)
- NO. OF HOUSEHOLDS x NO. OF WORKERS
  (2-4 classes)
- POPULATION IN HOUSEHOLDS x AGE
  (6-8 classes)
- NO. OF HOUSEHOLDS x HOUSING UNIT TYPE
  (3-4 classes)
- POPULATION IN HOUSEHOLDS x RACE
  (2 classes)
- NO. OF EMPLOYEES AT PLACE OF WORK x INDUSTRY
  (2-8 classes)
- LAND USE ACREAGES x TYPE OF USE
  (6-10 classes)

NOTE: ALL OUTPUTS PREPARED FOR EACH DISTRICT AND EACH FORECAST YEAR

FIGURE 5.1-D15: TYPICAL MODEL OUTPUTS

(EXTRACTED FROM PEAT, MARWICK, MITCHELL & CO. [1972[a]], PAGE 13)

currently being applied in two more. In several of these instances two separate versions of the model were developed, one employing a simple conceptual structure to serve as a basis for sketch planning and the other set in a more complex format as a foundation for more detailed analysis. Fi summarizes the set of applications which have been made of the model up to the present time.

GENERAL COMMENTARY

"EMPIRIC" is perhaps the most flexible and versatile of the five models included in this discussion. It is, at the same time, the weakest of the set in terms of a unique theoretical structure. It is essentially an empirically-based, econometric model of urban change. It does not build on a single, rigid theory of urban development. Rather it utilizes standard econometric techniques coupled with a series of very general hypotheses concerning the processes underlying in urban growth, to identify the major factors influencing the past development and history of the region and to extrapolate these in a meaningful way into the future. In many ways it is less a model than a parcel of techniques for model building.

This structure is both the main strength and the main weakness of the model.

In one sense it provides the analyst with a powerful and extremely flexible device for assessing established patterns of development over a particular time period. As such, it may be used effectively as a research tool, both to test specific theories of development and also to assess the impact which specific past developmental policies have exerted on the established pattern of urban growth. More importantly, in the context of this report, it may equally well be used (and this has been its major application to date) as a foundation for projecting the future pattern of growth in an urban area in response to a wide variety of alternative policy considerations or under a wide variety of different analytic conditions. The model builder may take full advantage of a rich data-set or a relatively complex theory of development, or he may rely only upon relatively simple data sources and a very crude conceptualization of the development process.

On the other side of the coin, however, the lack of a strong, unique theoretical foundation - such as that embodied, for example, in "PLUM" or "USM" - places a heavy burden on the ability of the analyst to develop his own conceptual structure and to translate this into a set of meaningful, valid statistical relationships. More than any of the other models discussed here, the effective calibration and application of "EMPIRIC" require a significant degree of familiarity both with the development process itself and also, particularly, with the fundamental principles of econometric technique. The model is, unfortunately, only too easy to mis-apply.[1]

This is by no means to argue that the model can only be used by the specialist, heavily trained in econometrics. Rather it is to emphasize that a significant degree of econometric expertise is required in the course of model calibration, and that the development of the model as a tool for continuing application within the work program of a conventional planning agency should be accompanied by a significant degree of staff training.

The model has a history of some significant operational success. It has been applied more widely in the USA than any other single formulation. It has not, however, stimulated anything like the amount of independent research activities as have flowed, for example, from the original "Lowry Model". In part, the widespread use of the model derives from its inherent flexibility and proven operational record; it is also a function of the fact that the model is supported actively by a major consulting organization, and has been continuously updated over the past 5 years to take full advantage of developments in computer hardware.

Its data requirements are extensive (though not significantly more so than those of "USM", "UPM" or, in its more extensive

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1) By far the most significant danger is that the analyst may be tempted to use the regression routines as a statistical fishing-pole, with little or no notion of the fish which he wishes to catch nor of the pond in which they reside. It is absolutely essential that any calibration of the model be founded on strong, a priori reasoning to support the structure of the calibrated equations.

version "PLUM"). They may, however, be readily integrated within the continuing work program of a typical transportation or regional planning agency which is already at least minimally committed to analytically oriented activities.[1] As in the case of most of the other models discussed in this section, much of the data assembled for calibration and forecasting purposes have widespread application in other, related areas of planning.

In several places where "EMPIRIC" has features which are generally in common with those embodied in "USM" and "PLUM", for example, it possesses a number of significant differences. The structure of the land consumption model, for example, is considerably more detailed than the land-accounting routines incorporated within those two models. It encompasses a somewhat broader set of land use categories and employs a more rigorous set of land consumption procedures. Equally important, the basic set of outputs which may be generated by the model provide in several instances for a more detailed breakdown of specific characteristics than do most of the other models - e.g., the distribution of households according to income category is generated directly by the main, simultaneous-equation module, while a standard set of supplementary sub-models yield parallel estimates of small-area population by age, households by size, households by numbers of workers, etc. In terms of explicit comparison with both "USM" and "PLUM", "EMPIRIC" does not require exogenous estimation of the future small-area distribution of "basic" or "primary" employment. It does not, however, incorporate many of the specialized outputs which are available from "USM" or "PLUM" - e.g., measures of air pollution or projected land value, etc.

Again, the potential complexity of the output has a negative as well as a positive element associated with it. It re-

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1) It may be noted here, parenthetically, that the data assembly routines contained within the model system have been utilized effectively for a number of purposes totally separate from those associated with the calibration of a land use model. They have, for example, been used in several instances to support other modeling activities. They have also been used as part of the overall software necessary to support development of a continuing, planning-oriented regional information system.

quires the assembly of a significantly larger data set, and it implies the expenditure of significantly increased resources - in terms of both time and money - on model calibration and application.

Finally, it should be noted that the model has a somewhat broader capacity for addressing policy issues of a variety of different types than do most of the other models in this section. It may be used, for example, to deal separately with issues relating to both highway and transit system development[1]. Alternatively, the model has been used recently to evaluate the implications of alternative fair-share housing policies, development controls, open-space policies and moratoria on additional sewer system construction.

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1) It should be noted that this capacity is contingent, in part, on the degree to which siginificant changes occurred in the transportation system existing in the study area over the calibration interval parallel to those anticipated for the future. The model may or may not, for example, be capable of representing the potential impact on urban growth of the construction of a new rapid transit system in an area where the provision of transit service over the calibration interval was both meagre and relatively unchanging. This point is discussed in some detail in Lathrop (1965).

APPENDIX D-4

THE ACCESSIBILITY-OPPORTUNITY MODEL

INTRODUCTION

The Accessibility-Opportunity Model was developed initially by Messrs. John R. Hamburg and George T. Lathrop while they were on the staff of the New York State Department of Public Works. It has been applied, in a number of different forms for several metropolitan areas in upstate New York. It has also been used in Cleveland and Pittsburgh. The model is described in more detail in Lathrop (1965).

General Description

The model is designed to allocate future urban development amongst a set of zones, taking into account such factors as relative accessibility, the availability of vacant land and exogenous assumptions concerning future land-use develop-' ment policies. The model is a straightforward adaptation of the intervening opportunities model of trip distribution developed by Morton Schneider. As originally formulated, the model is designed to distribute residential and non-residential trip ends, which are considered to be proportional to the basic activities generating the trip.

The model is essentially a static equilibrium model. It is used as a growth model by employing it in recursive format over successive short intervals and allocating only those activities expected to be added to the region during each forecast interval.

The model was programmed originally for the IBM 7094. It has since been modified for use on the Burroughs B-5500 computer. All programs are written in FORTRAN and are compatible with modification for operation on IBM 360 and similar equipment. To the writer's knowledge, no such modification has yet been made.

The model builds directly upon standard data assembled by a typical transportation planning agency. Its outputs are designed to be directly compatible with the input requirements of conventional transportation planning computer programs.

MODEL STRUCTURE

As noted above, the model is a direct adaptation of the intervening opportunities model of trip distribution. It consists of one set of "n" equations for each activity to be allocated, where "n" represents the number of zones within the study area for which projections are to be developed. The general form of the equations may be expressed as:

$$A_{ij} = A_i \left(e^{-LO_{<j}} - e^{-L(O_{<j} + O_j)} \right) \quad , j = 1....n$$

where:

A_{ij} = amount of activity i allocated to zone j

A_i = total amount of activity i to be allocated

$= \sum_{j=1}^{n} A_{ij}$

L = probability of a unit of activity being sited at a given opportunity

O_j = number of opportunities in zone j

$O_{<j}$ = number of opportunities ordered by time-distance from the origin up to, but not including zone j

The model builds directly on the notion that as an urban area grows activities compete for sites at points successively further distant from the center and consider their sites in terms of the availability of land for development. The number of opportunities in zone "j" -"O_j" - is considered in the model to be proportional to the amount of land available for development in zone "j" at a specified density. The resultant density gradient of activities that follows from an application of the model is then dependent both upon the parameter "L" and on the number of available sites in each zone.

CALIBRATION AND APPLICATION

The calibration of the model consists of estimating the value of the parameter "L", representing the probability of a unit of activity being sited at a given opportunity location, based upon the base-year distribution of activities, the base-year transportation network and data on base-year trip making. Separate values of "L" are calibrated for each activity to be allocated.

The model is then applied by computing the values of "L_i" based upon a projected future-year transportation network and an estimate of the total amount of land available for development at that point in time in each zone. These values are then inserted into the general equation together with an estimate of the projected regional total of the activity to be allocated for each forecast year. The result is a proportional allocation of activity between all candidate zones, proportional to the parameter "L" and the relative "attractiveness" spatially of that zone with respect to all other zones.

If two or more activities are to be allocated - e.g., residential and non-residential - to a common set of opportunities, the assumption must be made that one activity will consistently outbid the other in the competition for available land. That is, the equations for one activity must be solved completely before the equations for the next activity are solved.

Data Input Requirements and Output Capabilities

The model is designed deliberately to utilize the standard types of data assembled by most transportation studies. Its basic data requirements are extremely simple. They include small-area estimates of total population and land use for the base-year selected for model calibration, base-year trip data and a base-year inter-zonal travel time matrix, estimates of the total regional population and employment for each forecast year, estimates of future residential and non-residential trips for each forecast year, projected inter-zonal travel time matrices for each forecast year corresponding to the networks which it is anticipated will be in existence by that time, and estimates of any projected changes in residential density or trip end density for each forecast year.

The outputs of the model are similarly simple. They are essentially small-area estimates of the levels of each activity to be allocated by the model for each forecast year. In the case of a simple residential/non-residential model these would be small-area estimates of residential and non-residential activity.

Resource Requirements for Model Application

No documentation is available on the estimated resource requirements associated with the application of the "Opportunity-Accessibility" Model.

Examples of Model Application

The model has been successfully applied in a number of different metropolitan areas in upstate New York, in Cleveland and in Pittsburgh.

GENERAL COMMENTARY

The Opprtunity-Accessibility Model is probably the simplest of the five models outlined in this discussion. It is designed explicitly to function within the transportation planning process. It makes little pretense to be sensitive to policy considerations other than those which are either directly or closely related to transportation planning activities.

It is particularly interesting to note that, whereas the original trip distribution model on which the allocation formulation is based was designed to distribute trips from each origin zone to all other potential destination zones, the allocation model is designed only to distribute activities (i.e., trip ends) from a limited number of centers. If the model were extended so that all residential activity, for example, were distributed with respect to all employment centers, the resultant residential allocation function would be essentially similar to that employed in "PLUM". In this sense, the model represents, therefore, a highly simplified version of the standard Lowry type of model, employing an opportunity rather than a gravity or similar form of distribution function. It should be noted here that Goldner has reported on a number of experiments involving the use of opportunity formulations in

recent developments of "PLUM".

Finally, it should be noted that the Opportunity-Accessibility model suffers from a major shortcoming in that it is not provided with active staff support for application in areas outside New York State. The model is not truly "transferable" in the sense of many of the requirements for transferability identified in the earlier section of this report.

APPENDIX D-5

THE URBAN PERFORMANCE MODEL

INTRODUCTION

The Urban Performance Model ("UPM") differs considerably from those discussed earlier in this section. It has a totally different conceptual foundation and possesses a considerably more complex structure.

It assumes that the distribution of growth across an urban region may be related to a series of measures reflecting, respectively, the relative, spatial distribution of region-wide "opportunities" and the "quality" of the immediate, local environment surrounding a potential development site. The model may operate in either a descriptive or a projective mode. In the former case, a comprehensive urban data base is used to construct quantitative measures of "opportunity" and "quality" for each of a series of small-areas within the region. These measures are then used to characterize what the authors term the "distribution of urban performance" across the region for a given point in time. In the projective mode of operation, these measures are input to a sequence of allocation functions designed to project the future distribution of activity in successive increments of approximately 2 years. The theoretical basis for the allocation is founded on the principles of conventional linear-utility theory. The model is designed to be explicitly "policy sensitive", both to transportation planning considerations and also to a relatively wide range of policy areas. Its outputs include projections of small-area population, land use and employment, together with the more complex measures of "Opportunity" and "Quality".

The original formulation of the model was developed under Dr. B.A. Arat as part of the activities of the Tel Aviv Metropolitan Transportation Master Plan Team. Further extensions of the model were performed by TRC Systems Sciences Company under contract to the U.S. Department of Transportation, Office of the Secretary. A trial application of the model in Minneapolis-St. Paul as part of this activity was only partially successful. Subsequent development work in Israel, however, has led to a successful further application in Tel Aviv. The most recent version of the model is prorietary to the Israeli firm Research and System Analysis, Ltd.

More detailed descriptions of the model are given by Brown and Kirby (1971[a] and 1971[b]) and in a User's Manual (R.S.A., Ltd., 1972).

General Description

Unlike the other models described in this section, the "UPM" is designed to be used as both an evaluative and a projective tool. In the evaluative mode, the model employs a series of quantitative indices, labeled "opportunity" and "quality" measures, computed on a small-area basis to assess the overall characteristics of a particular pattern of development for a single point in time. In the projective mode, these measures are combined with a series of linear-utility allocation functions to produce estimates of the change in distribution of activity across the region in approximately 2 year increments.

It is postulated that two major factors underlie the locational decisions of both residents and employers as an urban area grows. The first of these - labeled "opportunity" in the model - is concerned with the relative accessibility of different portions of the region to "attractions" which are metropolitan-wide in nature. The second - labeled "quality" - is concerned more with the nature of the immediate, local environment surrounding a particular site.

These concepts are translated operationally by the model into a series of ingeniously constructed "opportunity" and "quality" indices. The "opportunity" indices take the form of a set of stratified accessibility measures. These are similar in general form to the measures used in other models - e.g., "EMPIRIC". They differ in detail, however, through the application of a complex set of weights reflecting, for example, the relative participation of different segments of the resident population in different types of employment or the observed congruity between different classes of employment and different types of land use. The "quality" measures are considerably less complex in structure. Based on the discussion in Brown and Kirby (1971[b]), they appear to take the form, operationally, of base-year counts of resident population within each small area, stratified by income class. These latter stratifications of the population according to income classification also provide the basis for the identification of the "resident groups" used in the "opportunity" index calculation.

Separate measures of "opportunity" and "quality" are computed for each small-area or zone within the region for a particular point in time. These indices are themselves used as the basis for a sequence of evaluative analyses of the existing pattern of urban development. These latter take the form both of simple mapping of the indices across the entire urban area, and also identification of the proportions of the resident population, etc. provided with given levels of "opportunity" and "quality". In concert, these analyses provide the foundation for the statements of "urban performance" which give the model its title.

The outputs of the descriptive portion of the model serve as the foundation for its application in a predictive mode. The model is designed to operate for forecasting purposes over somewhat shorter increments of time than those employed by the other models discussed here. They usually are taken as approximately 2 years. The model assumes that at a point in time the distribution of activity across the urban area is moving toward a state of equilibrium. Growth in either population or employment, or modifications in established development policies, may cause a perturbation is this trend and cause the distribution of activities to move towards a different equilibrium state.

The core of the allocation component of the model is built around a series of linear-utility functions. These are designed to reflect the impact of a small increment of land-use activity within a particular zone on the values of the "opportunity" and "quality" indices computed for that zone. That is, to calculate the marginal effect on the indices of small changes in specific land use activities.

Four separate fundamental economic constructs are employed within the allocation process. These are:

. relative utility of location

. marginal utility of location

. marginal alternative value

. relative preference function.

The model hypothesizes that the bulk of locational decisions for both residential- and employment-oriented activities are made on the basis of a trade-off between the values of "opportunity" and the values of "quality" associated with alternative sites within the metropolitan area. The relative Utility of Location expresses this postulate in formal terms. More specifically, it is assumed that a relative utility may be defined for a particular activity and a particular "resident group" in each zone of the region expressed as a product of the opportunity and quality values for that zone raised to some exponential power. The exponents employed in this expression represent the locational elasticities of that particular "resident group" for that activity with respect to "opportunity" and "quality", respectively.

Marginal Utility of Location is then defined as the difference between the relative Utility of Location after a marginal change in land use activity has been made in a given zone and the equivalent values before that change was made. The change in land use activity may be either positive or negative.

The Marginal Alternative Value represents the net effect of removing a small increment of non-residential land use activity of a particular type from a given zone and at the same time adding a separate increment of residential activity, for a particular "resident group" to the same set. This is expressed formally as the sum of the Marginal Utility of Location for a small increment in residential activity and a particular "resident group" in that zone plus the Marginal Utility of Location associated with a decrease in non-residential land use in the same zone.

The Relative Preference Function is used to represent the impact of reduced residual holding capacities on the incremental allocation of activities. It is postulated that as the amount of vacant land in a zone is used up the economic price of the remaining land will rise. This price increase presents an impedance to succeeding potential locators in that zone, ultimately causing them to select another zone having a lower utility value but a larger amount of available land. This concept is expressed operationally by multiplying the Marginal Utility of Location by an activity-specific holding capacity factor for that zone.

MODEL STRUCTURE

The overall structure of the model is divided into three major components. The first component - labeled UPMDATCK - consists of a set of programs designed to check basic data inputs. The second component - labeled UPMPQ - contains the routines embodied in the descriptive portion of the model. The third module - labeled UPMDIS - contains the predictive components of the model. The outputs of UPMDIS are identical with those of UPMPQ.

The detailed procedure followed in UPMDIS may be broken down into eight steps, which are repeated for each time increment:

. Step #1 - Exogenous Land Adjustments

The stock of land use in each zone is adjusted to reflect the impact of specific, exogenously determined development or renewal projects. The adjustments may be either positive or negative and may be concerned with any or all land use activities. After all individual zonal adjustments have been made the appropriate regional totals are updated.

. Step #2 - Adjustment of Residential Land Use Holding Capacities

The residual holding capacities for residential activity are checked in each zone for agreement with established plans and future zoning requirements. For those zones having negative residual residential holding capacities the level of population is adjusted accordingly and the appropriate adjustments made to the regional total.

. Step #3 - Adjustment of Non-Residential Land Use Holding Capacities

The non-residential land use holding capacity for each zone is checked for agreement with established plans and future zoning requirements. Again, zones having negative residual holding capacities have appropriate adjustments made in their level of non-residential land use activity; these adjustments are again transferred to the appropriate regional totals.

. Step #4 - Adjustments for Estimated Regional Declines in Non-Residential Land Use Activity

If an overall decline is projected in one or more non-residential land use activities for the region as a whole during a particular growth increment, marginal alternative values are created for that activity(ies) for each zone and rank ordered. An increment of non-residential land use activity from the appropriate category is then removed from the zone having the highest marginal alternative value. This process is repeated until a total amount of activity equivalent to the projected region-wide decline has been removed.

. Step #5 - Reduction of Residential Activity Due to Internal Migration

Marginal utilities of location for each resident group are calculated for each zone based on the presumed removal of a small increment of population in each group. A small increment of population is then removed from the zone having the largest marginal utility. The process continues until no positive marginal utilities remain, with the resultant stock of population reductions being added to a regional store for subsequent reallocation in step #7.

. Step #6 - Removal of Resident-Dependent Non-Residential Activity

This process is similar to that outlined above under step #5. Marginal utilities of location are rank ordered for each zone based on the removal of a small increment of non-residential land use activity within the zone. The calculation is based on the fraction of non-residential land use which is assumed to be dependent on residential activity. A small increment of activity is removed from the zone having the largest

marginal utility in a repetitive manner, as outlined above, until no positive marginal utilities remain. Again, the total set of reductions in activity are added to a regional store.

. Step #7 - Allocation of Residential Land Use

Allocation of population, by resident group, is achieved by rank ordering the zonal values of relative preference based on the presumed addition of a small increment in population to each zone. The zone and resident group with the highest value of relative preference then has an increment of population added to it, and the process is repeated iteratively until the total regional store of population to be allocated for each resident group is reduced to zero.

. Step #8 - Allocation of Non-Residential Land Use

The final step in the allocation process treats the allocation of non-residential activity in a manner analogous to that outlined under step #7 above for residential land use.

The series of eight steps outlined above are repeated recursively for each successive time increment.

Data Input Requirements and Output Capabilities

The model requires the assembly of a considerable amount of input data for a single point in time. The actual quantity of this data may vary depending upon the sophistication of the application. If only a relatively simple application is envisioned based, for example, on the designation of "resident groups" in terms of income, non-residential activity in terms of land-use acreages and/or employment level and "quality" in terms of a single index such as "number of rooms per persons" then the basic data requirements for model calibration and application include:

- Small-area data on the distribution and income characteristics of the population for a given base-year;

- Small-area data on the distribution and characteristics of employment, for five employment categories, for a given base-year;

- Small-area data on eight categories of land use for a given base-year;

- Small-area data on the number of rooms per person for a given base-year;

- Zonal level transportation networks and travel data for a given base-year, broken down according to trip purpose;

- Small-area data on residential and non-residential holding capacities, development densities and development constraints, identified for both a base-year and for each two-year forecast increment.

If a more sophisticated application is envisioned based, for example, on a more complex structuring of "resident groups" into a more coherent set of behavioral units then the data requirements may expand significantly.

The model outputs include small-area projections of each of the population, employment and land-use categories used as input to calibration, together with a series of indices - e.g., the "opportunity" and "quality" indices discussed earlier. These indices, represented in either map or tabular form represent one of the most valuable aspects of the model's projective capacity.

Resource Requirements for Model Application

No detailed documentation is available on the estimated resource requirements for the application of "UPM". RSA, Limited have stated that they would be willing to undertake a calibration and application of the model, including the development of one set of forecasts for a 20-year period for a given metropolitan area for between $30,000 - $50,000. This figure, however, assumes that all necessary data inputs are available in machine processable form and also assumes a minimum level of interaction between RSA staff and the staff of the planning agency sponsoring the study. No documentation is available on the resources expended in applying the model in Tel Aviv.

GENERAL COMMENTARY

"UPM" is in many ways the most complex and the most intriguing of the five models discussed in this section. It shows a general similarity to the other models in a number of respects, but is also markedly different from them in a number of other respects. Areas of similarity include the use of what are in essence accessibility measures to represent the distribution of "metropolitan opportunities", the recursive structure of the predictive component of the model, and the formalized sequencing of the projective allocation process. Significant differences exist between "UPM" and the other models in the use of utility-theoretical concepts as the basis for the allocation process, in the descriptive constructs for characterizing the level of "urban performance" for a region at a given point in time, and in the extremely short time interval used for recursive projection purposes.

The several unique features of "UPM" have considerable conceptual appeal. They suffer, however, from both a lack of proven viability and also from undue simplification when couched in operational terms. For example, the notion of dividing the total residential population of a metropolitan area into a series of homogeneous groups, each of which is distinguished from the other in terms of similarities and differences in locational behavior, is intuitively appealing. The definition of these groups in terms of four simple income ranges is, however, somewhat unsatisfactory. Considerable research performed by others in the field[1)] suggests that income alone is not a terribly good discriminator of locational behavior in the sense posited by "UPM". Similarly, the use of a single measure to characterize the "quality" of a single zone significantly reduces the appeal of the model. No empirical justification is presented for the use of either of these two operational surrogates.

Of far more significance, however, is the fact that the projective components of the model have apparently not been fully exercised to date - at least no documentation of their use appears in any of the materials currently available

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1) For example, the research of Peterson at Northwestern University.

describing the application of the model. The calibration of the set of utility functions around which the predictive component is constructed it by no means a trivial undertaking. The precise procedure by which this is to be achieved is not apparent from the documentation currently available.

Given the fact that the projective components have not yet been fully tested, perhaps the most intriguing aspect of the model lies in its ingenious set of descriptive output measures. This applies particularly to the simple, but very effective techniques used to measure and display the distribution of "urban performance" across an urban area and also, particularly, to the concept of identifying differential "resident-group" participation in different forms of employment activity. Both of these concepts could be applied effectively to several of the other models - e.g., "EMPIRIC" and "PLUM" - discussed in this section.

APPENDIX E

REFERENCES AND BIBLIOGRAPHY

REFERENCES AND BIBLIOGRAPHY

The reference list gives publication data on references contained in the text and appendixes.

The bibliography gives works that may be of interest for further study, categorized by the types of models to which they refer. Works designated by an asterisk contain reviews of transportation planning models.

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APPENDIX F

REPORT OF INVENTIONS